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THE STEAM CONSUMPTION OF LOCOMOTIVE ENGINES FROM THE INDICATOR DIAGRAMS

BY

J. PAUL CLAYTON

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

BULLETIN NO. 65 JANUARY, 1913

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By J. Paul Clayton, Assistant, Mechanical Engineering Department,
Engineering Experiment Station

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THE STEAM CONSUMPTION OF LOCOMOTIVE ENGINES FROM THE INDICATOR DIAGRAMS

I. Introduction

1. *Preliminary.*—Steam locomotives in service on the road are tested from time to time to obtain data as to their capacity and efficiency, both being matters of vital importance in the successful and economical operation of trains. The tests are made for various purposes, among which the most important are those for the determination of the indicated or dynamometer horse power, the measurement of the steam and coal consumption per horse power developed either in the cylinders or at the tender drawbar, and the adjustment of the valve gear.

Two general methods of testing locomotives for economy and capacity are in use: (1) On the test plant, where all quantities measured may be ascertained with great accuracy for any given set of conditions and where conditions can be controlled. (2) On the road in regular service by measuring the total coal and water used for all purposes, and by determining the power developed by the engine either in the cylinders by means of the indicator, or at the tender drawbar through the aid of a dynamometer car.

The first method is the only one which permits the accurate determination of the effects produced by the varying conditions of service, including the steam consumption per indicated horse power hour developed at a given rate of power.

The second method is of use only to measure the capacity and average economy over a given run or over a long period of time. The steam consumed at the several rates of power cannot be segregated in this method due to the continual change of profile, necessitating corresponding changes in the rates of power, and to operating restrictions imposed by different service conditions.

The use of steam for auxiliaries such as the air pump, the train-heating system, blower, electric train-lighting sets, and also the loss of steam or water through the safety valves, blow-off valves, and boiler leaks render impossible the determination of the actual steam consumed per unit of power developed by the engines, since from 2% to possibly 15% or 20% of the steam generated is used by the auxiliaries, or is lost. It is thus practically impossible under ordinary conditions to measure the actual steam consumption of the engines.

While indicator diagrams are generally taken during a locomotive test, the use of these diagrams has been limited to the determination of the indicated horse power, the correctness of the adjustment of the valve gear, the effect of the exhaust nozzle on the back pressure, and the diagram factor as a guide for future engine design. It has been considered impossible to obtain a reliable estimate of the steam consumed by the engines from the diagrams, because of the variable and unknown "initial condensation" of steam up to the point of cut-off. Further, no data have been secured from the diagrams regarding piston and valve leakage, and it is practically impossible correctly to locate on the diagram the events of the stroke, cut-off, release, true compression, and admission.

2. *Development of a New Analysis of Cylinder Performance.*—As the result of an investigation of the forms of the expansion and compression curves which occur in indicator diagrams, new methods were developed for obtaining a measure of the actual steam consumption from the diagram alone, for detecting leakage into or out from the cylinder while the engine is in normal operation, for determining the amount of the clearance displacement, and for determining the location of the events of the cycle.

The development of these methods has been described in detail in Bulletin No. 58 of the Engineering Experiment Station and in a paper[1] before the American Society of Mechanical Engineers. A short résumé of the results will be given here.

The investigation disclosed the fact that the indicator diagram contains in itself the evidence necessary for an almost complete analysis of cylinder performance, the results of which have not heretofore been considered possible.

In obtaining these results the indicator diagram was transferred to logarithmic cross-section paper and a figure constructed which is called a logarithmic diagram. By the aid of this diagram it was found that the expansion and compression curves of all elastic media used in practice obey substantially the polytropic law $PV^n = C$, or in other words that the curves become straight lines on logarithmic paper. From this fact there were developed rational methods of approximating the clearance of a cylinder, of closely locating the cyclic events, and of detecting moderate leakage with the engine in regular operation.

It was discovered that the value of n in the law $PV^n = C$ is controlled directly in steam cylinders by the quality of the steam mixture which is present at cut-off, called x_c, and that the relation of x_c and n is practically independent of cylinder size and of engine speed for the same class of engine as regards jacketing and back pressure. This fact enables us to determine the actual amount of steam and water present in a cylinder at cut-off from the experimentally determined relations of x_c and n, and thus to determine from the diagram the actual steam consumed. This method of determining steam consumption will be called the $n - x_c$ method in subsequent discussion.

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[1] A. S. M. E. Journal, p. 539, April, 1912.

For details of the processes described and for the exhibit of the facts leading to the results mentioned, the reader is referred to Bulletin No. 58.

3. *Application of the Analysis to Locomotives.*—In view of the difficulties of determining the actual steam consumption of locomotive engines on the road, and of segregating the consumption at different rates of power, the advantages to be derived from applying the new analysis to locomotives are apparent.

For this application it is extremely fortunate that there are in existence several hundred complete tests of almost all common types of simple and compound locomotives. These tests were run on locomotive test plants under laboratory conditions and were carried on with great care.

4. *Sources of Data.*—The tests which have been analyzed in this investigation comprise the Purdue tests made by Dr. W. F. M. Goss, the St. Louis tests made by the Pennsylvania Railroad System, and later tests made at Altoona, Pennsylvania, by the Pennsylvania Railroad Company.

The Purdue tests were run at the locomotive testing plant of Purdue University, Lafayette, Indiana, on a 16 in. x 24 in. simple locomotive. The first series of tests analyzed were made in 1904-1905 with saturated steam under different pressures varying from 120 lb. to 240 lb. gage, and are noted in "High Steam Pressures in Locomotive Service," by Dr. W. F. M. Goss. In the second series of tests which are described in "Superheated Steam in Locomotive Service," by the same author, a Cole superheater giving about 160° F. of superheat was used under various pressures.

The St. Louis tests which are described in "Locomotive Tests and Exhibits," published by the Pennsylvania Railroad Company, were run at the Louisiana Purchase Exposition at St. Louis, Missouri, in 1904. The test plant was built by the Pennsylvania Railroad System, and erected in the Transportation Building of the Exposition. Two simple and six compound locomotives were tested at this plant, and the results from all of these tests have been analyzed.

The Altoona tests were run on the same plant as the St. Louis tests after that plant had been removed to its permanent location at Altoona, Pennsylvania. Of the tests made there since 1904, two simple locomotives using saturated steam and one simple locomotive using steam superheated about 250° F. were among those analyzed.

The locomotives from which the tests were obtained comprise practically all important types in use in America and Europe except the Mallet compound locomotive. Six simple and six compound locomotives are represented.

5. *Results of the Analysis of Locomotive Diagrams.*—The development of the $n - x_c$ method of determining from the indicator diagrams the actual steam consumed, and of the other methods relating to leakage, clearance, and cyclic events results in enlarging the scope of locomotive tests and in making more accurate and valuable the information to be gained from them.

It also makes more valuable the application of the results of locomotive tests on test plants to the conditions obtaining upon the road. The application of these methods to road tests accomplishes the following results:

(1) The steam consumption of the engines may be obtained from the indicator diagram alone to a degree of accuracy greater than that obtained by most full road tests.

(2) The $n - x_c$ method of accounting for the actual steam consumption of the engines in connection with the regular road test will give reliable information as to the amount of steam used by auxiliaries and that lost and wasted, such information being exceedingly difficult to obtain at the present time.

(3) The existence, and in some cases the amount of leakage through valves and into and out from the cylinders may be ascertained; the spring of valve gears may be determined from the logarithmic diagrams as shown by the change in location of the cyclic events under various conditions.

(4) The clearance may be determined from the diagram to a satisfactory degree of accuracy.

6. *Acknowledgment.*—Acknowledgment is made to Dr. W. F. M. Goss for the use of material from the tests which he conducted at Purdue University; to Purdue University through Dean C. H. Benjamin for the use of the original indicator diagrams from the Purdue tests; to the Pennsylvania Railroad Company through Mr. C. D. Young, Engineer of Tests, for the use of the original indicator diagrams and of material from the St. Louis tests, and also from later tests made at Altoona.

Valuable suggestions have been received from Dr. W. F. M. Goss, Professor C. R. Richards, and Mr. F. W. Marquis.

Thanks are also due to Mr. A. F. Westlund for his efficient services in preparing the data, and in checking the manuscript.

II. Application to Simple Locomotives of the $n - x_c$ Method for Determining Steam Consumption

7. *Operating Conditions and Methods of Application to Tests.*—All of the tests of simple and compound locomotives analyzed were run with the locomotive operating under approximately constant conditions of speed, cut-off, and boiler pressure as shown by the laboratory designation. The duration of tests was in most cases from two to three hours, although some few were run for only 30 minutes. All readings except the weight of coal, this weight not being used in this investigation, and the indicator diagrams were taken every ten minutes.

All water lost from injector overflow was returned to the feed tank, or was caught, weighed, and allowance was made; all steam lost from safety valves, calorimeters, etc., was allowed for and subtracted from the quantity used per hour by engines; correction was not made in the log for the moisture carried by the steam, as the actual amount of steam and water present was desired; allowance was made for differences in height of water in the gage glass between the start and end of a test; therefore as far as can be ascertained, the weight of total steam and water used by engines per hour was correct, barring boiler leakage and the usual experimental errors incident to short boiler tests.

To represent the tests, one complete set of indicator diagrams taken at the same reading was selected, with an average mean effective pressure nearest to the average mean effective pressure of the whole test. These readings were taken when the boiler pressure was not more than 4 lb. from the average pressure prevailing during the test. Almost all of the sets of diagrams were within ½ of 1% of the average mean effective pressure for the test, hence the set selected could be taken fairly to represent the whole test.

From the set so selected logarithmic diagrams were constructed in accordance with the method described in Appendix I. The average values for n, x_c, and the absolute pressure at cut-off, called p, were determined from the logarithmic diagrams in the manner described in Appendix I, Article 3.

For the purpose of obtaining reliable results the following conditions were imposed:

(1) The steam pressure was maintained fairly constant. Tests having bad "steam failures" were rejected.

(2) The feeding of water was regular for the very short tests, short tests having irregular feeding were not used.

(3) Representative diagrams were chosen.

(4) Tests rejected by the Pennsylvania Railroad for evident inconsistencies were not used.

(5) Boiler pressures which varied between wide limits were not used. Only those diagrams were used which were taken when the boiler pressure did not vary more than 4 lb. from the average for the test.

All tests not rejected for the conditions mentioned were analyzed and used. The tests rejected amounted to 5% of the total number available.

8. *Relations of x_c and n for Simple Locomotive Engines.*—The relations of x_c and n from the cylinders of six typical simple locomotives were examined. The tests gave data as to the effect on the relation of change of cut-off pressure, speed, cylinder size, the use of saturated and superheated steam, and of various types of valves as they affected valve leakage and steam distribution.

A total of 189 tests was analyzed. The general classification of the locomotives tested and the number of tests analyzed for each one is given in Table 1. The principal dimensions of the six locomotives are given in Appendix II.

The general logs of the 189 tests are given in Tables 5-10 in Appendix II. Only those quantities are given which relate to the water fed and the values of x_c and n.

9. *Relations of x_c and n for the Purdue Locomotive.*—The values of x_c and n from the 104 tests of the Purdue locomotive are plotted in Fig. 1. These tests were run at the boiler pressures of 120, 160, 180, 200, 220, and 240 lb., and for each pressure at speeds of 97.5, 146, 195, and 243.5 r. p. m. The points comprise 35 tests with superheated steam, and 69 tests with saturated steam. The cut-off varied from 12% to 46% of the length of the stroke. In spite of the widely varying conditions of pressure, speed, cut-off, and quality of steam used, it is seen that the general relation of x_c and n is well defined.

The values of x_c and n for the 19 tests run at 200 lb. pressure are plotted in Fig. 2, showing the effect of various speeds for tests run at the same boiler pressure. This figure contains lines which will be explained in connection with the determination of the influence of speed upon the relations of x_c and n.

10. *Relations of x_c and n for all Simple Locomotives Tested.*—All of the values of x_c and n from the 189 tests of the six locomotives were plotted in Fig. 3. This figure proves the relation of x_c and n for one class of engine, and it also proves the comparative independence of this

TABLE 1

General Data for Simple Locomotives Tested.

Number or Name of Locomotive	Owner	Classification of Railroad Company	Type	Where Tested	Size of Cylinders, inches	Boiler Pressure	Quality of Steam Used	Type of Valves	Speeds Tested. r. p.m.	Number of Tests Analyzed
Purdue	Purdue University	Schenectady No. 2 and 3	American Eight Wheel	Purdue University Lafayette, Ind.	16 x24	120–160–180 200–220–240	Saturated and Superheated	Balanced Slide	97.5–146–195–243.5	104
7510	Penn. R.R.	K2	Pacific	Altoona, Pa.	24 x 26	205	Saturated	Piston	80–100–120–160–180	28
3395	Penn. R.R.	K29	Pacific	Altoona, Pa.	27 x 28	200	Superheated	Piston	100-120-160-180-240-280	18
5266	Penn. R.R.	E2a	Atlantic	Altoona, Pa.	20½ x 26	205	Saturated	Double-Ported Balanced Slide	80–120–160–200	13
1499	Penn. R.R.	H6a	Consolidation	St. Louis, Mo.	22 x 28	205	Saturated	Balanced Slide	40–80–120–160	11
734	L.S.& M.S. R.R.	B1	Consolidation	St. Louis, Mo.	21 x 30	200	Saturated	Double-Ported Balanced Slide	40–80–160	15

TABLE 2

General Data for Compound Locomotives Tested.

Number	Owner	Classification of Railroad	Type	Where Tested	Size of Cylinders, Inches	Boiler Pressure	Quality of Steam Used	Type of Valves	Speeds Tested	Number of Tests Analyzed	
										H.P.	L.P
585	M.C.R.R.	W	Consolidation	St. Louis, Mo.	2 Cylinders 23 & 35 x 32	210	Saturated	H. P. Piston; L. P. Double-Ported, Balanced Slide.	40–80–160	9	9
929	A.T. & S.F. R. R.	900	Santa Fe	St. Louis, Mo.	4 Cylinders 19 & 32 x 32	225	Saturated	Piston	40–60–80	9	9
2512	Penn. R.R.	De Glehn Compound	Atlantic	St. Louis, Mo.	4 Cylinders $14\frac{3}{16}$ & $23\frac{11}{16}$x25¼	225	Saturated	H.P. Balanced D Slide. L.P. Not Balanced	80–160–240–280	8	5
535	A.T. & S.F. R.R.	507	Atlantic	St. Louis, Mo.	4 Cylinders 15 & 25 x 26	220	Saturated	Piston	80–160–240–280	8	10
628	Royal Prussian Railway	S8	Atlantic	St. Louis, Mo.	4 Cylinders $14\frac{5}{32}$ & 22 x 23⅝	200	Superheated	H.P. Piston; L.P. Double-Ported, Balanced Slide	80–160–240–280	9	9
3000	N.Y.C.&H. R.R.R. Co.	I1	Atlantic	St. Louis, Mo.	4 Cylinders 15½ & 26 x 26	220	Saturated	Piston	80–160–240–280–320	9	11

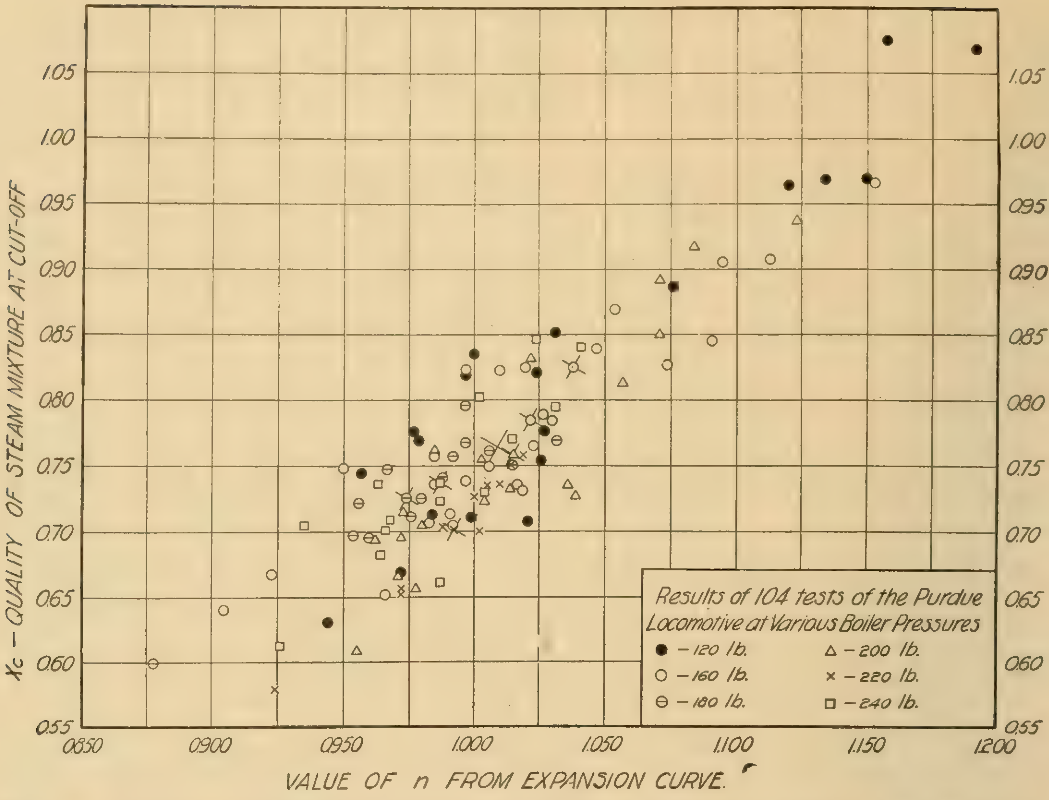

FIG. 1. GENERAL RELATIONS BETWEEN x_c AND n FOR THE PURDUE LOCOMOTIVE.

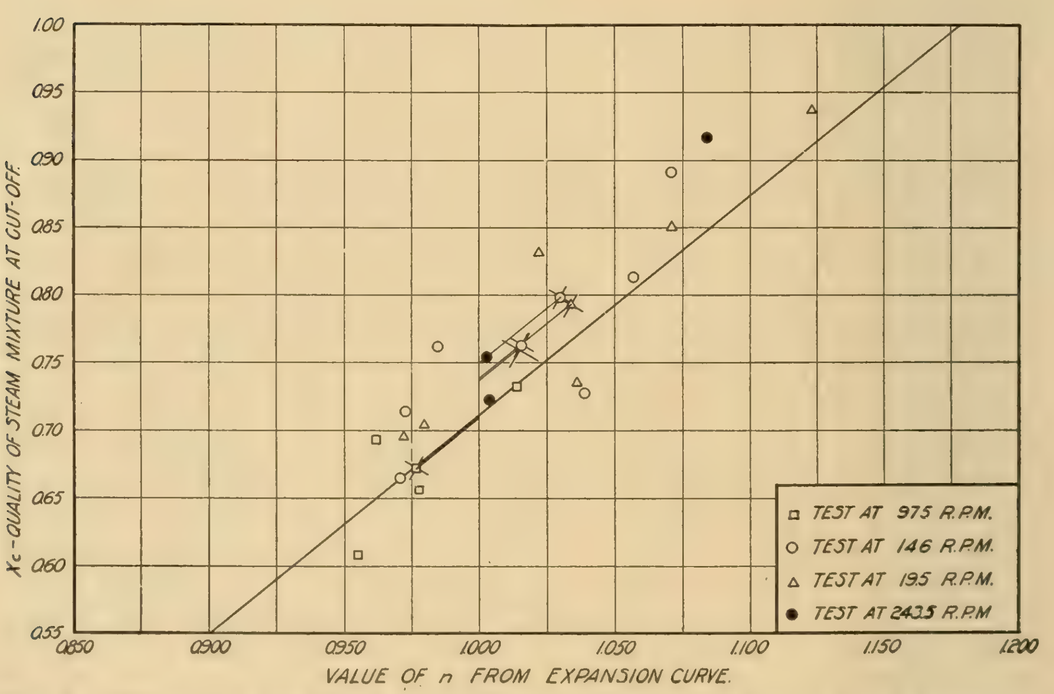

FIG. 2. RELATIONS OF x_c AND n FOR VARIOUS SPEEDS AT 200 LB. GAGE PRESSURE. FROM THE PURDUE LOCOMOTIVE.

relation from the effect of unduly varying pressures, speeds, sizes, types of valves, and quality of steam used.

In the tests shown, the speeds varied from 40 to 280 r. p. m.; the boiler pressures from 120 to 240 lb.; the displacement of the cylinders from 2.8 to 9.1 cu. ft. (the cylinder sizes varying from 16 in. x 24 in. up to 27 in. x 28 in.); the quality of the steam from saturation to 250° F. of superheat and the cut-off from 12% to 50% of the stroke.

The tests were made with locomotives having common slide valves, balanced slide valves, and piston valves. Almost every condition which is ever present in a simple locomotive cylinder is present except speeds below 40 and above 280 r. p. m., and lengths of cut-off over 50%.

The conditions mentioned were not obtained for the following reasons: Speeds below 40 r. p. m., which were made in general at the limit of adhesion, were not attempted because of the very uneven rotational speed which caused slipping. This was due to lack of sufficient flywheel inertia effect, this effect being present on the test plant and not on the road because on the road the whole mass of the locomotive and train caused the wheels to revolve at a uniform rate. The torque exerted by the brakes attached to the supporting wheels was fairly uniform, and the speeding up and slowing down of the drivers during parts of a revolution caused slipping, thereby necessitating the regrinding of the surface of the supporting wheels.

Lengths of cut-off exceeding 50% were not attempted because of the danger of slipping, as the coefficient of adhesion of the driving wheels upon the supporting wheels of test plants is far less than the coefficient for clean dry rails.

Speeds exceeding 280 r. p. m. were obtained, but the effect of the inertia of the indicator pencil motion at speeds of 320 r. p. m. and over, distorted the expansion curves so greatly that good values of n could not be obtained from them.

In determining the curve to represent the general relations of x_c and n shown in Fig. 3, several factors must be examined. It will be seen that as 55% of the tests were from one locomotive and if each test were given equal weight, then this locomotive, although the smallest one tested, would govern over one-half of the evidence on which the relations for all locomotives would be founded. The tests run on each locomotive were numerous enough that the average value of x_c and n for each one could be closely determined for its entire range of action. As the locomotives tested represented practically all of the typical designs of simple engines in modern use as to size, pressure, and valves, it was decided to locate the "center of gravity" of the tests for each locomotive and to give equal weight to the tests from each.

The center of gravity, or average value of the values of x_c and n for each locomotive was obtained by averaging the co-ordinates of x_c and n, and plotting the result as a cross through the same kind of point which was used to represent the tests of each locomotive.

After the center of gravity of the tests of each locomotive was obtained, the location of the center of gravity for all the locomotives was determined in a similar manner by using the centers found for each one, the center for all tests being plotted as a large cross in Fig. 3.

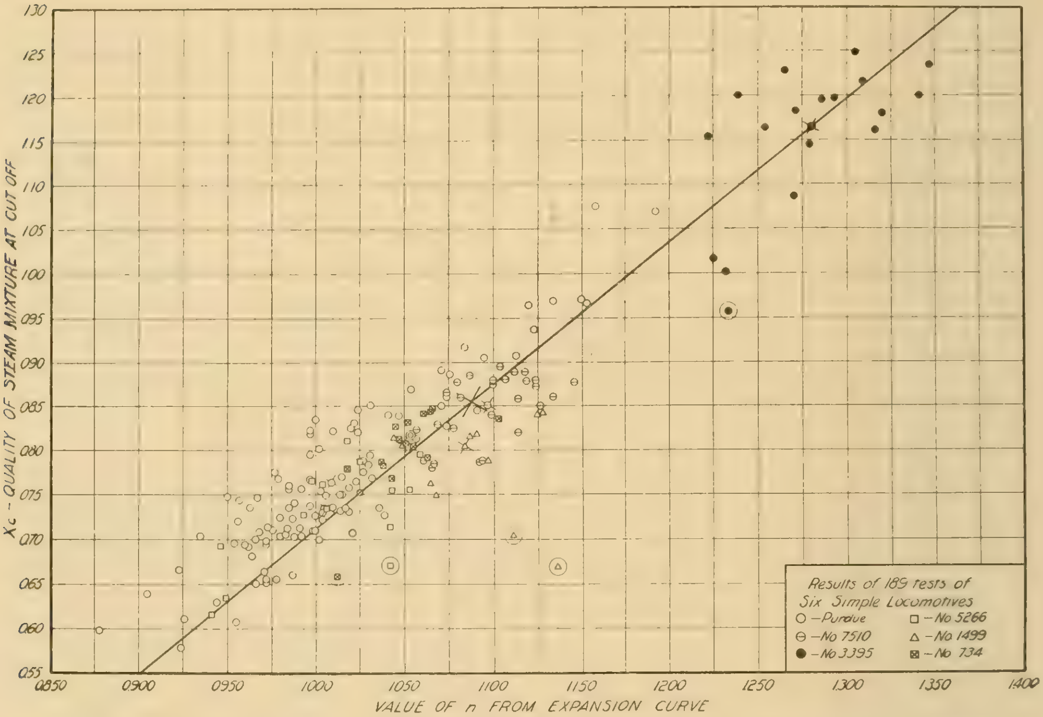

FIG. 3. RELATIONS OF x_c AND n FOR ALL SIMPLE LOCOMOTIVES TESTED.

A straight line was then drawn through the center of gravity of the tests of all locomotives, and was made to pass through the center of the tests of locomotive No. 3395.

A straight line was used from the following considerations: Previous experience[1] with the relations of x_c and n in Corliss engines had shown that the relation is a natural straight line for any one engine, and that the relations of other engines of the same class might differ a small amount as to the exact values obtained but that the slope of the line obtained was substantially the same. The relation of x_c and n

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[1] Bulletin No. 58, p. 12. Engineering Experiment Station.

for adiabatic expansion as developed in Bulletin No. 58, is also a straight line having a different slope.

The line as drawn also represents the centers of the tests of all the locomotives with an average deviation of 2.4%, measured from the zero value of x_c. The average deviation of the points above the curve is about the same as that of the points below the curve.

The center of gravity of all tests is shown by a concentric circle which is 2.4% higher than the curve, due to the fact that the Purdue locomotive has 55% of all the tests, and is the highest point in distance measured above the line.

The points shown which are drawn with a circle around them were not considered in drawing the line, as they were undoubtedly subject to certain inconsistencies in testing, the exact causes of which have not been determined.

The equation of the line selected is $x_c = 1.620\ n - 0.909$. This equation expresses the results of all tests (except the five encircled points) to an average deviation of 5%, regardless of sign, and to a normal maximum deviation of about 9%.

It must be remembered, however, that all the errors of very short boiler tests are present and their effect is included in the values of x_c which have been found. For this reason it is believed that the errors given are considerably larger than the true ones, and that the line given represents the true value of x_c for a given value of n much more closely than appears from the errors given.

The points plotted in Fig. 3, of which the average condition is represented by the line drawn, were examined for the effect on the value of x_c, for constant values of n, of varying the speed, cut-off pressure, back pressure, size of cylinder, the type of valves used as regards leakage, the use of saturated and superheated steam, and the length of cut-off. The seven variables given comprise all of the variables present in the tests of the six engines examined and also in each engine under different conditions of construction and of operation.

11. *Effect on the Relations of x_c and n of Varying the Speed.*—In locomotive service the speed of engines under sustained conditions of operation varies from about 40 up to perhaps 320 r. p. m., the latter speed corresponding to a piston speed of 1500 ft. per min. for a 28 in. stroke of the piston.

In stationary practice the speed of engines having the same length of stroke or longer is between 60 and 150 r. p. m., thus having a range of speed of only 90 r. p. m. between limits. Locomotive engines, however, have a range of speed of about 280 r. p. m. between limits, showing that the range is three times that of stationary engines of equivalent size or power. It may be expected, therefore, that varying the speed would affect in some degree the relations of x_c and n for locomotive engines.

The method employed to examine the effect of change of speed upon the relations of x_c and n is illustrated in Fig. 4, which is derived from

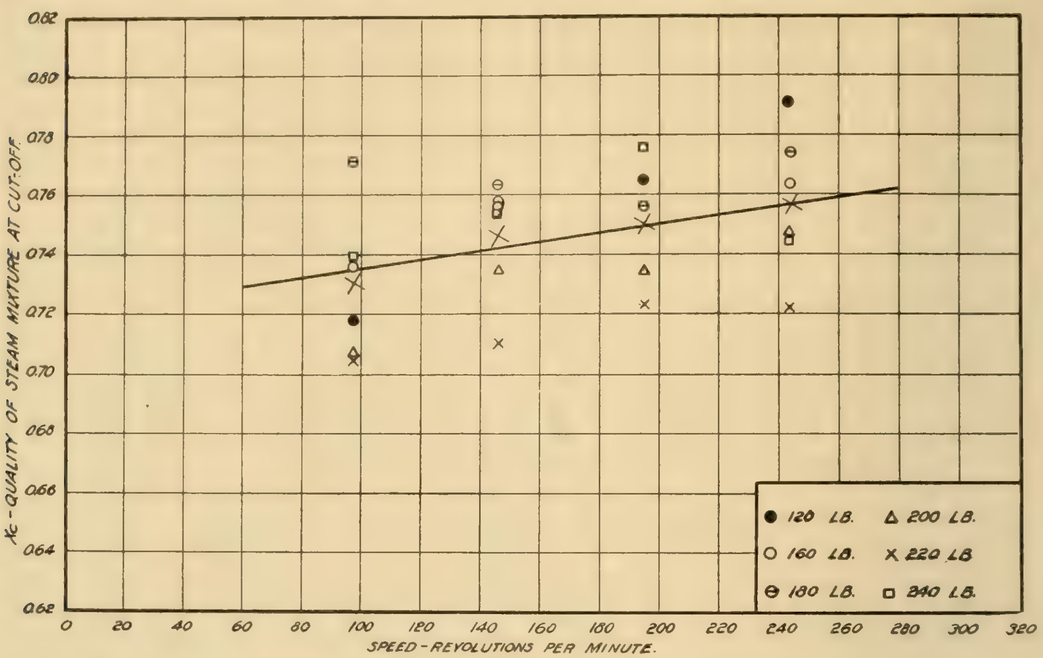

FIG. 4. RELATIONS OF x_c AND SPEED FROM THE PURDUE LOCOMOTIVE FOR THE CONSTANT VALUE OF $n = 1.000$

Fig. 2. Fig. 2 gives the points derived from all tests of the Purdue locomotive run at 200 lb. boiler pressure. The center of gravity of each group of tests run at one speed was obtained and was plotted as a cross through a point representing the speed examined. The full line representing the average relation for all locomotives is drawn as shown. Through the center of gravity for each speed a line was drawn, parallel to the full line, to the intersection of the line $n = 1.000$. The point of intersection therefore gives the value of x_c, for the constant value of $n = 1.000$, at the speed examined. The points of intersection thus obtained were plotted in Fig. 4, and are represented by the triangles. Points obtained from the tests at other pressures were also plotted in Fig. 4. This figure represents the relation of x_c and speed at the value of $n = 1.000$ for the series of pressures used.

It is evident from the points plotted in Fig. 4 that there is a definite tendency for a high value of x_c to be obtained as the speed increases, the value of n remaining the same.

The process just described was repeated for the tests of all the locomotives and, together with the centers of gravity of the Purdue tests, was plotted in Fig. 5. A group of points was obtained which like Fig. 4 showed that the average effect of increasing the speed was to increase the value of x_c, for constant values of n.

To represent the average effect of change of speed upon x_c, the points were divided into two groups and the center of gravity of each one was found as indicated by the crosses; a line was then drawn through the two centers as shown. The average deviation of the points irrespective of sign is 3.2% (measured from the zero of x_c), each point being weighted in proportion to the number of tests it represented, except the Purdue tests, which were rated at 4 tests each.

From Fig. 3 it is seen that the line crosses the value $n = 1.000$ at $x_c = 0.711$. On drawing the line $x_c = 0.711$ in Fig. 5 it is found to intersect the line representing the relations of x_c and speed at 143 r. p. m. This intersection indicates that the average relation of x_c and n represented by the line $x_c = 1.620\ n - 0.909$ is true for a speed of between 140 and 150 r. p. m. It also indicates: (1) That the average points obtained at speeds below 140 r. p. m. fall below the line; (2) That the average points obtained at speeds above 150 r. p. m. fall above the line; (3) That by making corrections for the speed at which the indicator diagrams were obtained, the average deviation resulting from determin-

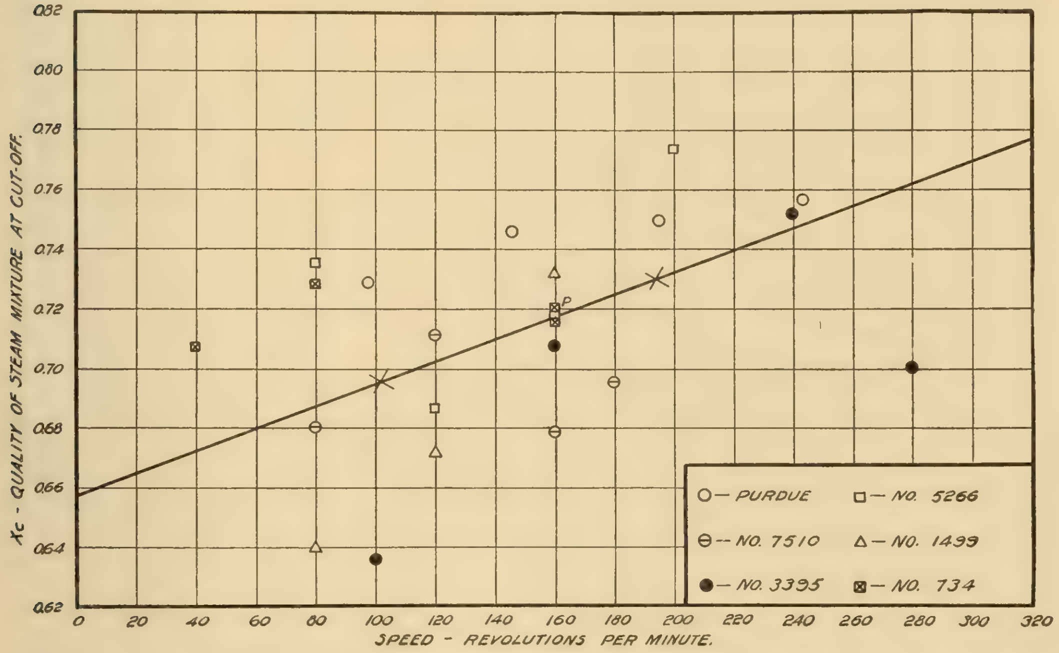

FIG. 5. RELATIONS OF x_c AND SPEED FROM ALL SIMPLE LOCOMOTIVES FOR THE CONSTANT VALUE OF $n = 1.000$

ing the value of x_c by the equations given is lowered from 5.0% to 3.2%.

The equation $x_c = 1.620\ n - 0.909$ was modified therefore by adding a corrective term for speed which expresses the relation of x_c and speed shown in Fig. 5. The modified equation is

$$x_c = 1.620\ n - 0.909 - 0.00037\ (143 - S)$$

where $S =$ speed in r. p. m.

The corrective term drops out at 143 r. p. m., it lowers the value of x_c for speeds below 143 r. p. m., and raises the value of x_c for higher speeds.

The causes which operate to produce the effect upon the value of x_c due to change of speed are discussed in Section IV.

12. *Effect of Varying the Cut-off Pressure.*—The effect on the value of x_c due to variation of the cut-off pressure of the diagram, speed and n being constant, was first observed from the Purdue tests, which include a wide range of cut-off pressures resulting from boiler pressures varying from 120 to 240 lb.

The points used were plotted in Fig. 6 and were obtained from Fig. 4 as follows, the example being taken from the tests at 20 miles per hour; the cut-off pressures for the tests run at 220 lb. pressure and at the speed of 97.5 r. p. m. (20 miles per hour) were averaged and found to be 176 lb. absolute; hence for n=1.000 and speed S=97.5 r. p. m., the value of x_c obtained is 0.704. In a similar manner the tests at

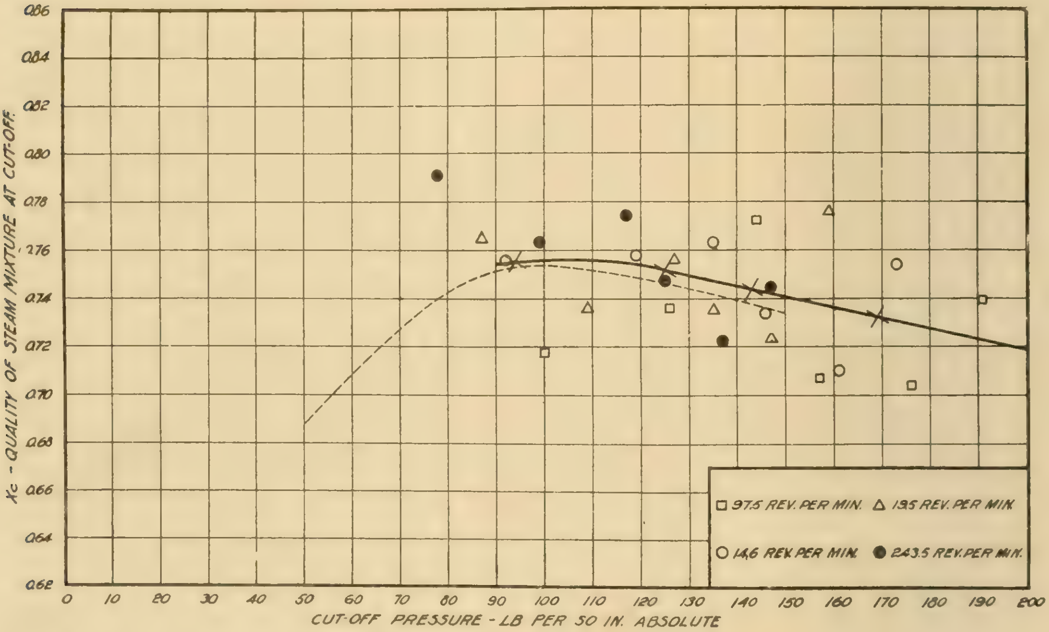

FIG. 6. RELATIONS OF x_c AND CUT-OFF PRESSURE FROM THE PURDUE LOCOMOTIVE FOR CONSTANT SPEEDS AND THE VALUE OF $n = 1.000$.

200 lb. pressure gave an average cut-off pressure of 157 lb. absolute and a value of 0.707 for x_c. This procedure gave the relation of x_c and cut-off pressure at the constant speed of 97.5 r. p. m. and $n = 1.000$.

In like manner the points for the other speeds were plotted in Fig. 6, thus giving the relation desired for a series of constant speeds. The points obtained were divided into four groups of six points each and the center of gravity of each group found as indicated. The centers were joined by a smooth curve. The curve as drawn indicated that the value of x_c at constant values of S and n reached an average maximum value for a cut-off pressure of about 105 lb. absolute, and that above 125 lb. a straight line was obtained.

It appears therefore that as the cut-off pressure increases the value of x_c decreases for constant values of S and n.

The effect on the relations of x_c and n, due to change of cut-off pressure, was compared with the same effect found in the previous tests[1] on a Corliss engine and the relations for this engine for the value of $n = 1.052$ and the speed of 120 r. p. m. was drawn dotted as shown.

The result of this comparison is a striking corroboration of the curve as drawn. The curves are almost exactly parallel in the range common to both. Both have a maximum point only 5 lb. apart, and both have about the same slope for pressures above 120 lb. The form of the curve representing the effect of cut-off pressure is thus fairly well established.

The points in Fig. 5 were examined for the effect of cut-off pressure in a way similar to that described for the Purdue tests, and the results are given in Fig. 7. The centers of gravity obtained in Fig. 6 were transferred to Fig. 7 to represent the Purdue tests.

The points of Fig. 7 give the average relation for all locomotives of x_c and cut-off pressure for a series of constant speeds and for $n = 1.000$. The group of points obtained shows the same trend as the Purdue tests although the vertical displacement due to speed is present and makes the relation somewhat indefinite.

It was assumed that the Purdue tests shown in Fig. 6, because of their large range of cut-off pressures and similarity to previous relations, represented the form of the curve, but was placed too high on the plot to represent the average relation for all locomotives. Therefore the center of gravity of all the points of Fig. 7 was found and a curve drawn through this center similar in form to the Purdue relation.

It is seen from Fig. 7 that the range of cut-off pressures in simple locomotives is between 120 and 180 lb. absolute, while the majority lie between 130 to 160 lb. The average cut-off is about 145 lb., this point being close to the average value of $x_c = 0.711$ for $n = 1.000$ given in Fig. 3.

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[1] Bulletin No. 58, p.15, Engineering Experiment Station. Journal A. S. M. E., April, 1912, p. 550.

It is also evident that the difference in the value of x_c for the average cut-off, 145 lb., to an average high value, 165 lb., is only 1.6%, while to an average low value, 125 lb., it is only 1.3%.

The effect of varying the cut-off pressure on the relation of x_c and n is so small of itself, and so much smaller than the effect due to change of speed, that it need not be considered.

13. *Effect of Varying the Size of Cylinders.*—The size of the cylinders varied from 16 in. x 24 in. up to 27 in. x 28 in., the latter having a displacement of 3.25 times the smaller one. No effect on the relation of x_c and n was found that could be traced to any change of size of the cylinders.

In applying the $n - x_c$ method to stationary engines, as noted in Bulletin No. 58, the sizes varied from 10.5 in. x 12 in. up to 34.2 in. x 60 in., the latter having 53.5 times the displacement of the former. No effect in the relation of x_c and n was found from this cause.

14. *Effect of Various Types of Valves.*—The locomotive engines tested were equipped with plain balanced D slide valves, balanced double-ported slide valves, and piston valves. It was thought that there might be some difference in the apparent relations of x_c and n due to the different types of valves allowing steam to leak at different rates from the steam chest direct to the exhaust passage.

The results indicate that the locomotive having the least apparent valve leakage had balanced D slide valves as did also the one having the greatest valve leakage. The results of the two piston valves tested indicate that they both leaked apparently at a rate intermediate between the two extreme cases, their rate of leakage being close to the average for all valves. None of the valves tested leaked materially into or out from the cylinder.

The probable leakage occurring through the valves is discussed in Section IV.

15. *Effect of the Use of Superheated and of Saturated Steam.*—The use of superheated steam in cylinders in place of saturated steam results in a higher value of x_c for the same conditions of speed and cut-off. The higher value of x_c which is obtained results, in turn, in a higher value of n. When the same value of x_c is obtained at the same speed with either saturated or superheated steam, the same value of n has been found to result.

16. *Effect of Varying the Length of Cut-off.*—The length of cut-off used in the tests varied from 12% to 50%. It has been found that, other conditions being the same, if a given value of x_c occurs in one test at 12% cut-off, and in another test on the same locomotive at 46% cut-off, the value of n resulting is the same, showing that the length of cut-off has no measurable effect on the relation of x_c and n.

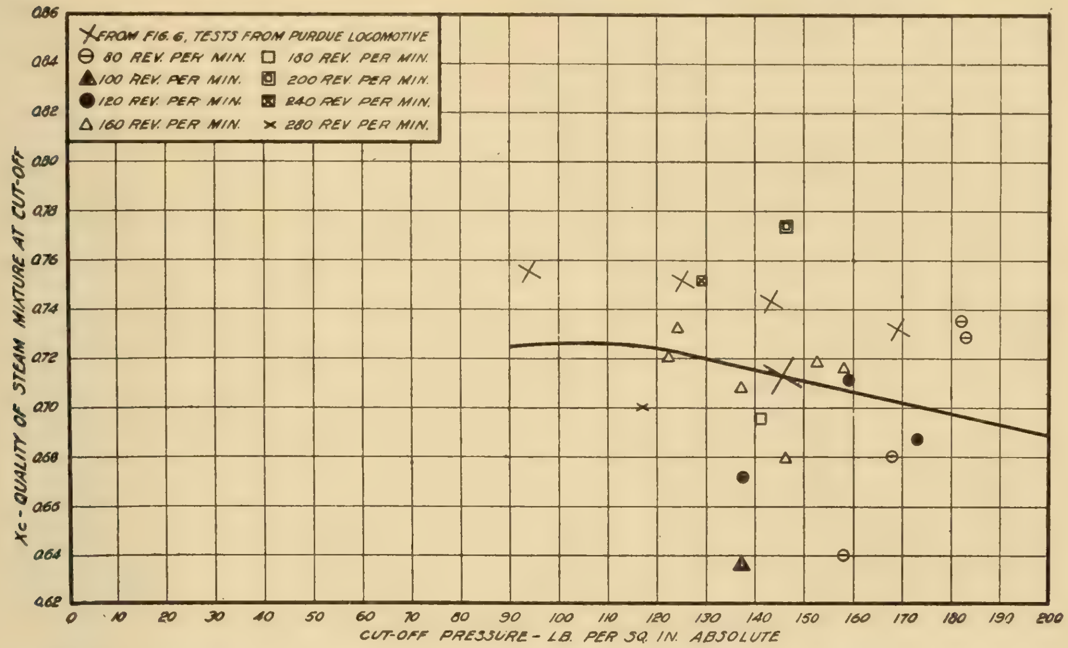

FIG. 7. RELATIONS OF x_c AND CUT-OFF PRESSURE FROM ALL SIMPLE LOCOMOTIVES FOR CONSTANT SPEEDS AND THE VALUE OF $n = 1.000$

17. *Effect of Varying the Back Pressure.*—The back pressure of the steam in the cylinders varied from 15 to 36 lb. absolute, a range of 21 lb. Varying the back pressure between these limits appears to have no effect on the relation of x_c and n.

When the back pressure is as high as 100 lb. absolute, however, as in the high pressure cylinders of compound engines, the relation of x_c and n is changed considerably, other conditions being the same.

III. APPLICATION OF THE $n - x_c$ METHOD TO COMPOUND LOCOMOTIVES

18. *Operating Conditions and Methods of Application to Tests.*—The same general test conditions prevailed for the compound locomotives as for the simple locomotives.

The method of selecting a set of indicator diagrams to represent the average conditions of a test was as follows: The average power of the test was represented by a combined sum made up of the sum of the values of the mean effective pressures for the low pressure cylinders, after each was multiplied by the value of the cylinder ratio, plus the sum of the values of the mean effective pressures for the high pressure cylinders. The set chosen, taken at the same reading, was one in which this combined sum was nearest to the sum of the test averages obtained in the same manner, and in which the boiler pressure was not more than 4 lb. from the average pressure prevailing during the test. The method of selection used eliminates any unequal division or work in the cylinders. The desired condition was, in most cases, fulfilled to within an average of ½ of 1% of the mean condition.

For the purpose of obtaining reliable and accurate results the following conditions, in addition to those mentioned on page 9, were imposed:

(1) Expansion lines showing extreme effects of inertia or sticky indicator pistons were not used, as fair values of n could not be obtained.

(2) The range of pressure from cut-off to release during expansion exceeded 12 lb. for low pressure indicator diagrams and 60 lb. for high pressure diagrams in order to provide a sufficient length of curve to be able accurately to determine the value of n.

The tests rejected for the reasons outlined above and those given on page 9 amounted to 10% of the total number available.

For the purposes of this investigation the high pressure and low pressure indicator diagrams were treated as separate tests, each receiving, however, the same weight of steam per revolution from the boiler.

19. *Relations of x_c and n for Compound Locomotives.*—Indicator diagrams from six typical compound locomotives were examined to determine the relations of x_c and n. Data were obtained as to the effect on the $n - x_c$ relation of change of speed, cut-off and back pressure, the use of saturated and superheated steam, the type of valves employed, and the effect of various rates of leakage of steam from the steam chest directly under the valves to the exhaust passage without this steam having entered the cylinder. This class of leakage in subsequent discussion will be called simply valve leakage.

The conditions existing during the tests varied between wide limits. The speeds varied from 40 to 320 r. p. m. The boiler pressures varied from 200 to 225 lb. The pressure in the receivers between the high and low pressure cylinders varied from 25 to 95 lb. gage. The back pressure in the low pressure cylinders varied from 1 to 20 lb. above the atmosphere. The cut-off varied from 25% to 65% of the length of the stroke. The valves used included plain, balanced, and balanced double-ported slide valves, plain piston valves, and special piston valves controlling the steam distribution to both high and low pressure cylinders. The receiver capacity varied from 0.4 to 2.2 times the displacement of the low pressure cylinders. The size of the high pressure cylinders varied from 14.16 in. x 23.65 in. to 23 x 32 in.; the low pressure cylinders varied from 22 in. x 23.65 in. to 35 in. x 32 in.

A total of 52 high pressure and 53 low pressure tests are presented. For very serious inconsistencies, due apparently to excessive valve leakage amounting to as high as 18.5% of the total steam used, all tests of locomotive No. 929 and all low pressure tests of No. 535 were not used to obtain the general relation of x_c and n. An analysis of the tests of these locomotives in comparison with the other tests is given in Section IV. After deducting the tests not used, there remained a total of 43 tests from the high pressure cylinders of five locomotives and 34 tests from the low pressure cylinders of four locomotives.

The general classification of the locomotives tested and the number of tests analyzed for each one are given in Table 2. The principal dimensions of the six locomotives are given in Appendix II.

The general logs of the 105 tests are given in Tables 11-16 in Appendix II. Only those quantities are given which relate to the water fed and to the values of x_c and n.

20. *Relations of* x_c *and* n *for High Pressure Cylinders.*—The values of x_c and n for all high pressure tests are plotted in Fig. 8.

The values obtained exhibit a much larger variation in position than those obtained from the simple locomotives in Fig. 3. The large variation obtained was found to be due to the addition of an important variable not present in the simple locomotives, namely, widely varying back pressures in the cylinders due to the varying receiver pressures employed in the different locomotives tested.

The center of gravity of the tests of each locomotive, the center of all tests, and the center obtained from the centers for each locomotive were all obtained in a manner similar to that fully described on page 13. The center of tests for No. 929 was plotted, but was not used. It is the point shown encircled in Fig. 8.

Unfortunately the range in the values of x_c obtained was so small relatively that a definite slope for a line to represent the average relations for all tests could not be obtained. It was decided, however, in the light of previous experience that the relations for the high pressure cylinders of locomotives possessed a slope similar to that obtained from simple locomotives, as the same general design and conditions prevail for both types.

A line was drawn, therefore, as shown in Fig. 8, to represent the average relation obtained from the high pressure cylinders of typical compound locomotives. The equation of this line is

$$x_c = 1.620\ n - 0.827.$$

The average deviation of all points from this line is 8.0%, while the normal maximum deviation is 12.0%.

The crosses representing the center of the tests for each locomotive are located at distances varying considerably from the average line due to varying back pressures for the same cut-off pressures and also to varying rates of valve leakage. The effect of both of these variables is treated later.

21. *Effect of Varying the Speed.*—The effect of varying the speed on the relations of x_c and n was investigated by the same general method as that employed for simple locomotives, except that, in order to eliminate the vertical displacement of the center representing all the tests for each locomotive, the values of x_c for this center were each corrected to the average line in Fig. 8.

The points obtained are plotted in Fig. 9. The method of correcting for vertical displacement of the center for the tests of each locomotive is as follows: A line was passed through this center parallel to the average line for all tests and extended to the intersection with the value of $n = 1.000$; the value of x_c at the intersection was read off; the amount in the value of x_c that the center was above or below the line

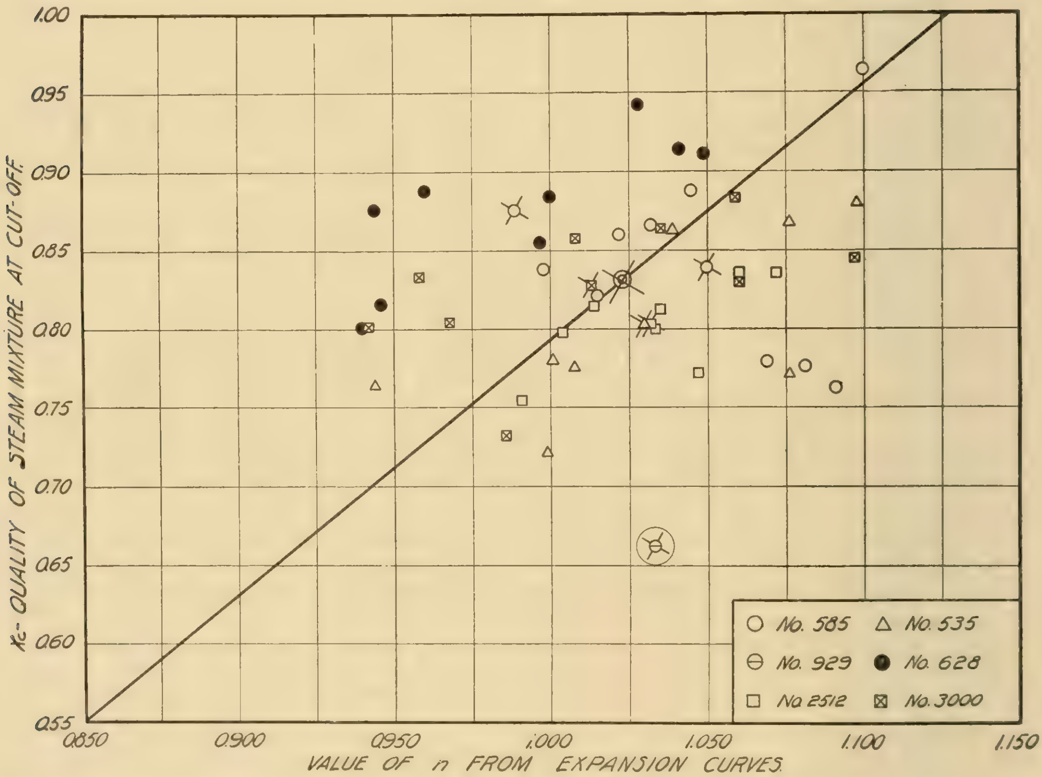

FIG. 8. RELATIONS OF x_c AND n FOR HIGH PRESSURE CYLINDERS OF COMPOUND LOCOMOTIVES.

was subtracted or added respectively to all readings for the intersections of the lines passed through the center of tests at each speed. Thus if a center for the tests of one locomotive was located 0.06 in the value of x_c above the line, the value of 0.06 was subtracted from the value at the intersection of each speed center at the value of $n = 1.000$.

The average effect of change of speed was determined as the straight line in Fig. 9. The average deviation of the points from the line is 3.4%. The result of accounting for the effect of speed on the equation expressing the relations of x_c and n is as follows:

$$x_c = 1.620\ \mathrm{n} - 0.827 - 0.00034\ (150 - S)$$

where S=speed of engine in r. p. m.

The speed effect obtained is very similar to the same effect for simple locomotives, but with a slightly different slope.

22. *Effect of Varying the Range of Pressure.*—It was found that other conditions remaining the same, raising the back pressure in the high pressure cylinder increased the value of x_c for the same value of n. It was also found that lowering the cut-off pressure, the back pressure remaining the same, had the same effect, though to a smaller degree. This last effect is corroborated by the same effect observed in the relations of x_c and n for simple cylinders given in Fig. 7.

Since the effects of raising the back pressure and of lowering the cut-off pressure each change the value of x_c in the same direction, they are cumulative and can be combined as the range of pressure from cut-off to the average back pressure. It was also found after careful examination that this range of pressure was the best measure of the observed effects for both the high and low pressure cylinders.

The back pressure in the high pressure cylinders is taken from the indicator diagrams as the average pressure at mid-stroke when the receiver capacity is large and the back pressure is therefore fairly uniform. When the receiver capacity is relatively small and the back pressure therefore is extremly variable, it is obtained from the diagrams at a point near the beginning of compression.

For the purpose of ascertaining the effect of varying the range of pressure on the relation of x_c and n, the effect due to change of speed was removed from the values of x_c obtained from the intersection of the line extended from the center of tests at one speed.

To show the effect desired the points obtained are plotted in Fig. 10. The corrections made for the effect of speed were obtained from Fig. 9. The method used was as follows: The average speed of all the tests of one locomotive was found and the value of x_c read off from the line in Fig. 9 for this speed; the correction for speeds below the average was made by adding to the value of x_c obtained, the difference between the value of x_c taken from the line at this speed, and the value of x_c found for the average speed; the correction for speeds above the average was made by subtracting in a similar manner the difference obtained.

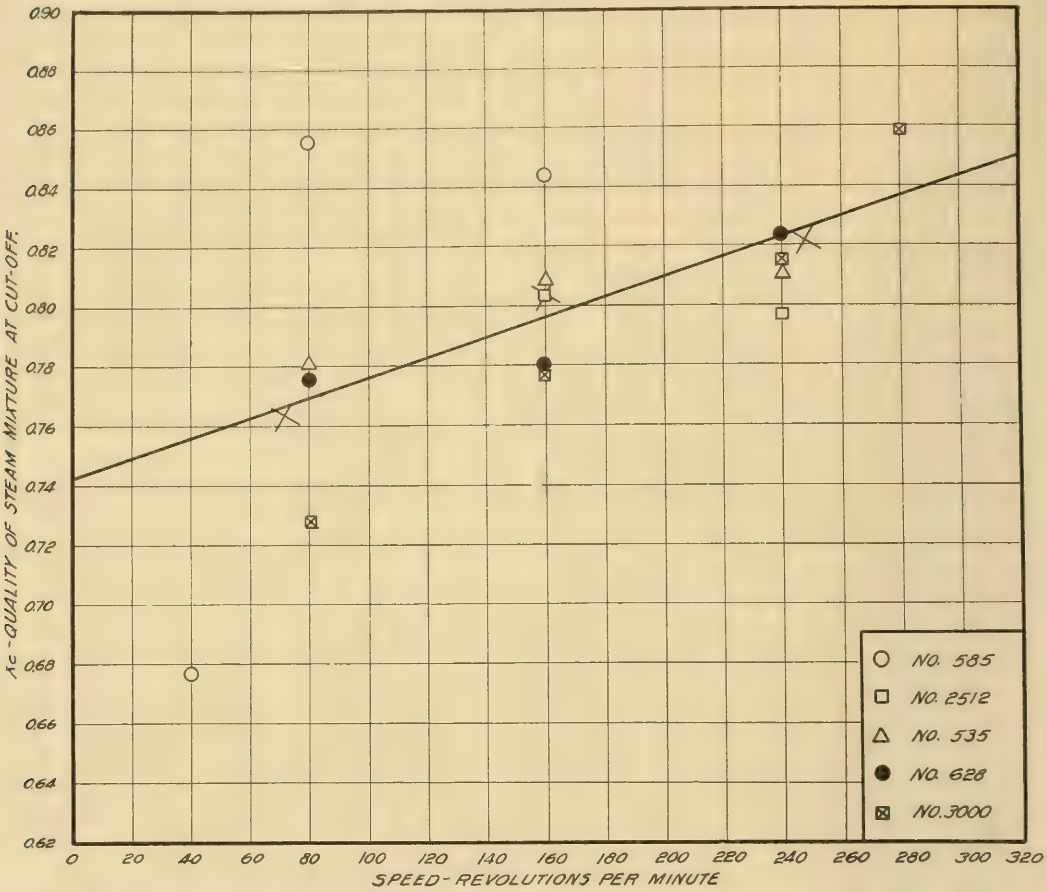

FIG. 9. RELATIONS OF x_c AND SPEED FOR HIGH PRESSURE CYLINDERS OF COMPOUND LOCOMOTIVES FOR CONSTANT VALUE OF $n = 1.000$, AND FOR CENTER OF TESTS CORRECTED TO AVERAGE LINE.

For example, if the average speed for the tests of one of the locomotives is 160 r. p. m., the average value of x_c at $n = 1.000$ from Fig. 9 is 0.796. If the center of tests at 80 r. p. m. be considered, the average value of x_c at 80 r. p. m. from Fig 9 is 0.769, being lower than the value of x_c at 160 r. p. m. by 0.027. The value of x_c from the center of tests at 80 r. p. m., after being increased by 0.027 to eliminate the average effect of speed, would be plotted in Fig. 10.

In examining the effect under consideration it is apparent that the relations of x_c and n for simple cylinders and for the high pressure cylinders of compound locomotives differ only in the effect produced by different ranges of pressures; that is, if the back pressure in the high pressure cylinder were lowered to about atmospheric pressure, this cylinder would operate, under the same conditions, as a simple cylinder and would therefore have the same relations of x_c and n. The effect of range of pressure for high pressure cylinders and for simple cylinders is, therefore, a continuous one.

The centers of all tests of each locomotive, the centers of tests at each speed for each locomotive, and two concentric circles and a cross representing the average relation for all simple locomotives are plotted in Fig. 10. The center of all high pressure points plotted was obtained and is plotted as a cross.

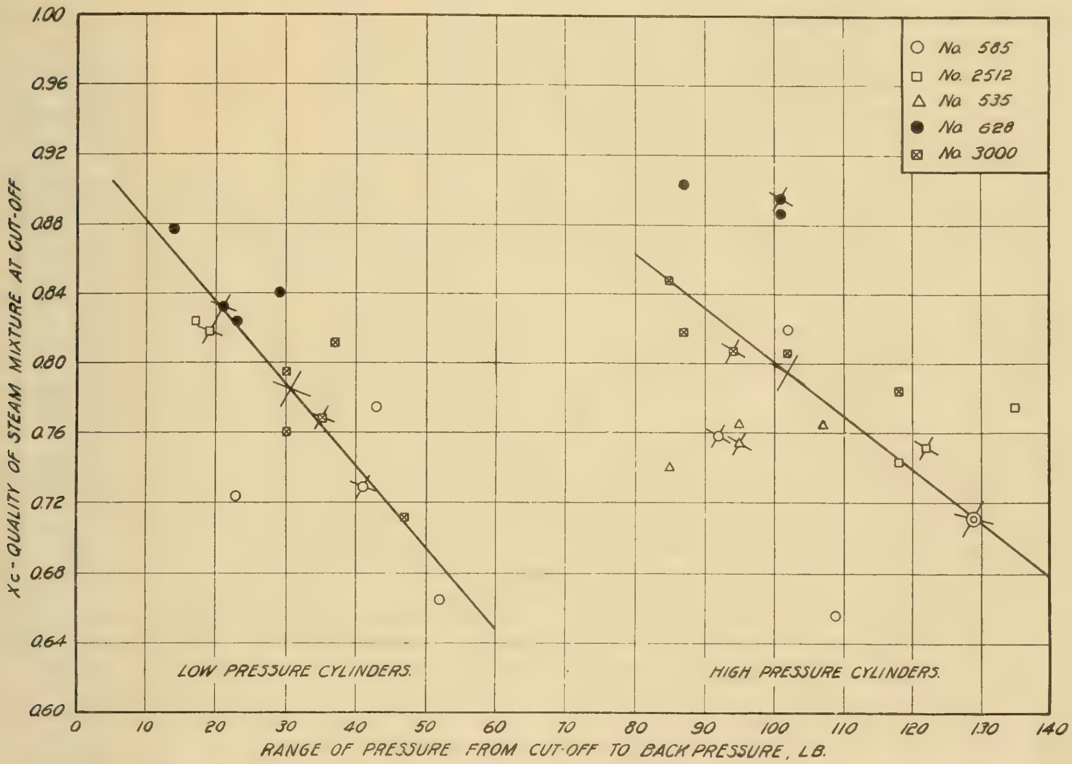

FIG. 10. RELATIONS OF x_c AND RANGE OF PRESSURE (CUT-OFF TO AVERAGE BACK PRESSURE) FROM COMPOUND LOCOMOTIVES FOR CONSTANT SPEEDS AND THE VALUE OF $n = 1.000$

A line passing through the center of high pressure tests and the center of simple tests was drawn to represent the average effect of range of pressure on the relation of x_c and n.

The equation after correcting for the average effect of range of pressure takes the form

$$x_c = 1.620\, n - 0.827 - 0.00034\ (150 - S) + 0.0031\ (102.5 - R)$$

where R = range of pressure from cut-off to the back pressure in lb. per sq. in.

The average value of x_c is obtained at 102.5 lb. range of pressure. The value of x_c is higher for ranges of pressure below 102.5 lb., and lower for ranges above 102.5 lb. The average deviation of the points from the line is 6.2%. This large deviation apparently shows the effects of varying rates of valve leakage as explained in Section IV.

23. *Relations of x_c and n for Low Pressure Cylinders.*—The methods employed to obtain the general relations of x_c and n for low pressure cylinders, and the effect on this relation of change of speed and range of pressure, were similar in all respects to the methods described for the high pressure cylinders.

The values of x_c and n obtained are all plotted in Fig. 11. The values obtained from locomotives No. 929 and No. 535 were not used on account of excessive valve leakage.

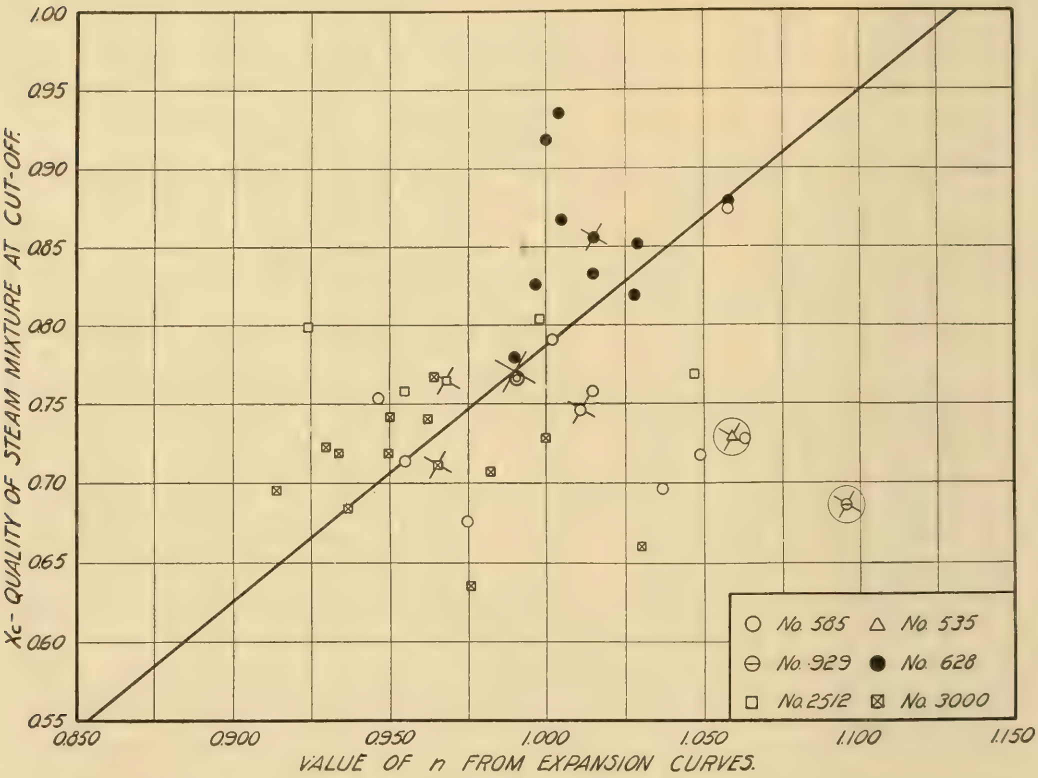

FIG. 11. RELATIONS OF x_c AND n FOR LOW PRESSURE CYLINDERS OF COMPOUND LOCOMOTIVES.

The line shown in Fig. 11 was drawn as outlined for the high pressure cylinders, using the same slope as the line obtained for the simple cylinders. The equation of the line is

$$x_c = 1.620\ n - 0.833.$$

The average deviation of all the points from this line is 7.8%.

24. *Effect of Varying the Speed.*—The points obtained which show the effect of varying the speed on the relation of x_c and n are plotted

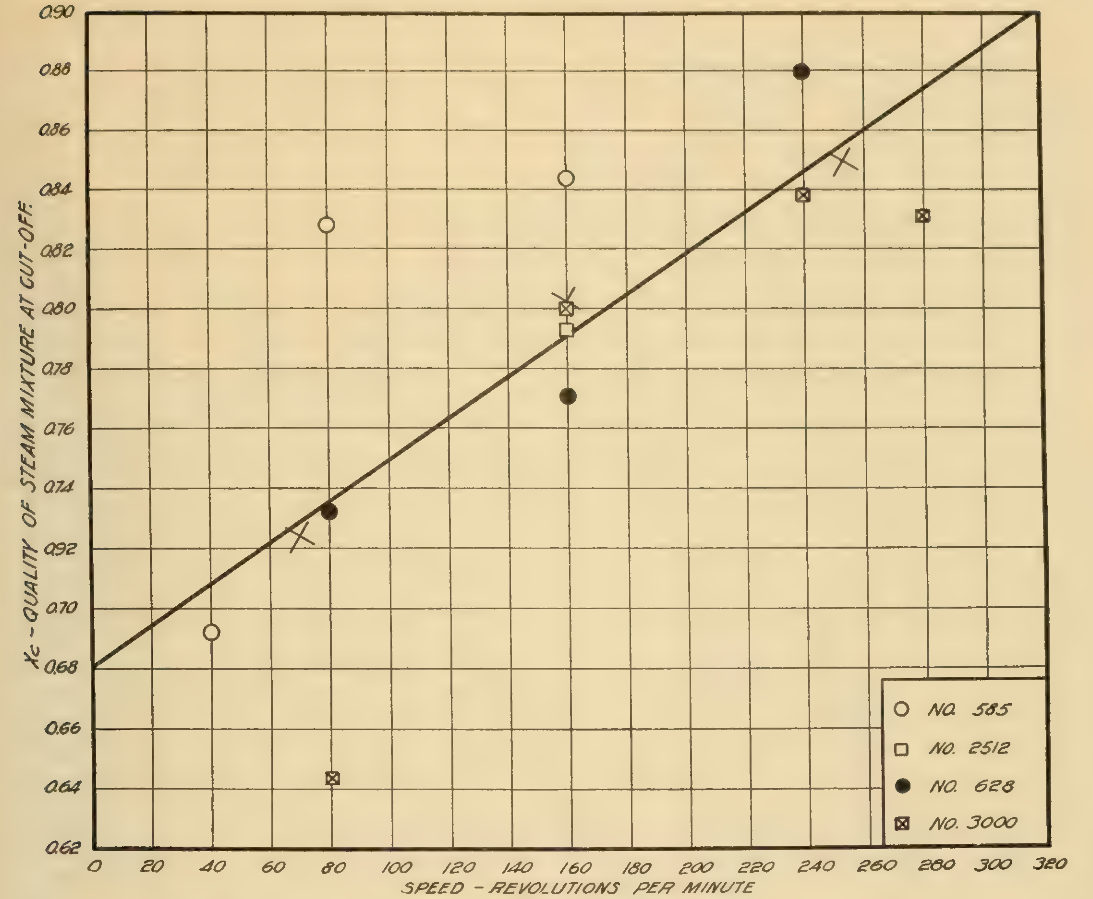

Fig. 12. Relations of x_c and Speed for Low Pressure Cylinders of Compound Locomotives for Constant Value of $n=1.000$, and for Center of Tests Corrected to Average Line.

in Fig. 12. The equation after correcting for the effect of change of speed is

$$x_c = 1.620\ n — 0.833 — 0.00069\ (154 — S)$$

The average deviation of the points from this line is 4.5%.

25. *Effect of Varying the Range of Pressure.*—The points obtained which show the effect on the relation of x_c and n of changing the range of pressure are plotted in Fig. 10. The equation as further modified by this effect is

$$x_c = 1.620\ n — 0.833 — 0.00069\ (154 — S) + 0.0047\ (30 — R)$$

The average deviation of the points from this line is 3.3%.

This extremely close agreement shows that the effects of varying the speed and range of pressure comprise all the important variables.

IV. Analysis of the $n — x_c$ Relations

26. *Causes Which Affect the $n — x_c$ Relations.*—The data which have been presented in the preceding pages will here be examined critically as to the causes which affect the relation of x_c and n due to

varying the range of pressure from cut-off to the back pressure and to varying the speed of the engine. These two variables are the only ones which cause an appreciable effect on the $n - x_c$ relation for locomotive engines.

It is well here to consider and compare the operating conditions of pressure and speed obtaining in stationary and in simple locomotive engines.

The boiler pressure of simple locomotives is always closely constant. The great majority have pressures of about 200 lb. gage, although the newer designs using highly superheated steam employ pressures of from 165 to 190 lb. gage. Pressures of from 200 to 230 lb. are employed in compound locomotives. The pressure used in stationary engines varies from 80 to 200 lb. gage.

The speed of locomotive engines in sustained operation varies from about 40 to 320 r. p. m. The speed of simple stationary engines of equal power varies from 60 to 150 r. p. m.

Relatively speaking, therefore, simple locomotive engines may be classed as constant pressure and variable speed; while compound locomotive engines may be classed as variable pressure and variable speed. Simple and compound stationary engines, however, may be classed as constant speed and variable pressure types.

From this classification it is apparent that the effects on the $n - x_c$ relation to be considered are as follows:

(1) In simple and compound stationary engines the effect of range of pressure is important while speed may be neglected.

(2) In simple locomotive engines the effect of speed is important while range of pressure may be neglected. (See Fig. 6 and 7.)

(3) In compound locomotive engines the effects of both range of pressure and speed are important. (See Fig. 9, 10, 12.)

The valves of a locomotive engine, when compared with stationary engines of the same size, are extremely large in proportion to the size of the cylinder. This is due to the high speeds which it is necessary to employ in order to obtain large specific capacities from the cylinders. As much as 2500 indicated horse power has been obtained continuously from two 27 in. x 28 in. cylinders. (See tests of No. 3395.) The piston valves of this locomotive are 16 in. in diameter.

If it be true as stated by various experimenters that single valves as a class leak steam directly under the valve from the steam chest to the exhaust passage, without this steam having entered the cylinder, then locomotive engines with their large valves might be expected seriously to show the effects of valve leakage at low speeds.

In Corliss and four valve engines any steam that leaks from the steam chest through the valves must leak into the cylinders.

27. *Effect on the Relations of* x_c *and* n *of Varying the Range of Pressure.*—The effect of lowering the range of pressure from cut-off to the back pressure is always to give smaller values of n for the same value of x_c, other conditions remaining the same. This result is due to the following reasons: For a given value of x_c, the value of n is the result of the volumes obtained by adiabatic expansion of the steam and water present plus an increase of volume of steam due to the return of heat from the cylinder walls and the consequent re-evaporation of part of the water condensed during admission. The rate of re-evaporation is controlled by the range of temperature due to the range of pressure, and it is greater or less according as the range of pressure decreases or increases respectively.

The effect of the range of pressure upon the $n - x_c$ relations for simple locomotives is small, as will be seen in Fig. 6 and 7; it is larger for the high pressure cylinders of compound locomotives, as is shown in Fig. 10; it is still larger for low pressure cylinders, as is also shown in Fig. 10. The slopes of the lines in these figures are 0.12, 0.76, and 1.17 respectively, showing the increasing effect of this variable as the range of pressure decreases.

28. *Effect on the* $n - x_c$ *Relations of Varying the Speed.*—The effect on the relations of x_c and n of increasing the speed is to give higher values of x_c for the same value of n, other conditions remaining the same.

The relations of x_c and n for Corliss engines did not show any definite increase in the value of x_c for speeds of from 90 to 150 r. p. m.

The effect on the value of x_c due to increase of speed is well shown for the relations of the Purdue locomotive in Fig. 4. In this figure it is seen that the average value of x_c increased from 0.735 at 100 r. p. m. to 0.756 at 240 r. p. m., a change in value of 0.021.

The average effect due to changes of speed for all simple locomotives, shown in Fig. 5, is from 0.695 at 100 r. p. m. to 0.747 at 240 r. p. m., an increase of 0.52, which is 25 times the increase found for the Purdue locomotive.

It is apparent that the center of all tests of the Purdue locomotive, which showed the least increase of x_c for increase of speed, is relatively the highest center plotted in Fig. 3. It will be seen also from Fig. 5 that the points of No. 1499 show the largest increase of x_c for increase of speed, and that its center of tests plotted in Fig. 3 is relatively the lowest.

The only phenomenon which accounts consistently for the observed effects due to speed is valve leakage. By valve leakage is meant the leakage of steam directly through the valves without its having entered the cylinder.

As has been stated, locomotives are peculiarly open to valve leakage at low and moderate speeds because of their relatively large valves and the use of very high pressures. The large valves expose a large surface through which steam may leak while the high pressures employed tend to increase the leakage to much larger amounts than those found in low pressure stationary engines with small valves. The experiments[1] which have been made on valve leakage show that the leakage is proportional, in a given engine, to the outside perimeter of the valve seat between the steam chest and the exhaust passage and also to the difference of pressure between these two regions. Varying the speed of operating the valves was found to have no effect on the amount of leakage. It was found also that although a valve might be perfectly tight while at rest yet it would leak a large amount when in motion, due to the breaking up of the oil film and to condensation and re-evaporation from the bridges and surfaces of the valve seat after they had been exposed first to steam at the initial pressure and then to the exhaust pressure.

Since valve leakage is proportional only to the perimeter of the valve seat and to the difference of pressure, it would, therefore, be a constant weight per unit of time for any one engine. Hence it follows, as valve leakage is constant per unit of time, that increasing the speed of the engine and thus using more steam in the cylinders would lessen the effect of valve leakage, measured as the per cent. of the total steam used. For example, if an engine running 50 r. p. m. leaks 500 lb. of steam per hour through its valve while receiving 4500 lb. per hour in the cylinder, the leakage is 10% of the total steam supplied; on the other hand, if it runs 150 r. p. m. and uses therefore three times the steam in the cylinders, 13,500 lb., then the valve leakage is only 3.6% of the total steam supplied.

All the evidence at hand shows that the existence of valve leakage and its relatively diminishing amount with increase of speed are the only conditions which account satisfactorily for the observed facts as shown in Fig. 4, 5, 9, and 12. That is, it is probable that there is very little if any effect on the n—x_c relations of varying the speed, but the existence of leakage and its increasing relative amount when speeds are decreased lead to an apparent value of x_c which is lower than the real value for the steam actually admitted to the cylinders. It is also probable that the value of x_c for engines having the larger values of valve leakage would increase faster with increase of speed than engines having very small leakage, because the increase of speed would increase the apparent value of x_c at a much faster rate. This condition is exactly the one which occurs, as is shown in Fig. 3, 4, 5, 9, and 12.

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[1] Leakage through a Piston Valve, by George Mitchell, Power, Oct. 11, 1910, p. 1805.
Callender and Nicholson's Experiments on Valve Leakage.

The slope of the line representing the effect of varying the speed for any one locomotive is apparently the best index as to the amount of valve leakage which exists.

It is probable that the relative location of the centers of tests in Fig. 3 is also a reliable index to the amount of valve leakage. The line drawn in Fig. 3 represents the average relation of the apparent value of x_c and the value of n. If a center of the tests for one locomotive lies above this line, then it apparently has a higher average value of x_c for the same value of n; the reverse is true if the center lies below the line. Since the effect of any leakage that may take place is to decrease the value of x_c for a given value of n, then the greater the leakage the lower would be the value of x_c.

The most striking case of the effects which have been described is found in the tests of No. 929, having tandem compound cylinders. The cylinders of No. 929 were almost exactly the same size as those of No. 585, yet, at the same speeds, cut-offs, and pressures the steam consumption of No. 929 averaged 19.6% more than that of No. 585. As the conditions of the tests of these two locomotives were almost exactly similar, they should have had practically the same steam consumption. It is, therefore, almost absolutely certain that a large proportion of the steam delivered by the boiler of No. 929 never entered its high and low pressure cylinders, where it could be used in producing power, but that it leaked directly through the valves. The effect of any such leakage was charged to the value of x_c which was obtained, and this value in consequence appears to be very much smaller than the values obtained from any of the other compound locomotives, although all of them except the No. 585 had much smaller cylinders. For instance, in the high pressure cylinders the average value of x_c obtained for the No. 929 is 0.662, while the average value of x_c for all other compounds is over 0.80. The same condition holds for the low pressure cylinders, although to a lesser degree.

In the light of the facts which have been presented and also from previous experience it is practically certain that the values of n obtained for the No. 929 are accompanied by values of x_c for the steam actually present in the cylinders as shown by the line in Fig. 11. It is also practically certain that had no leakage occurred, the steam consumption of the No. 929 would have been practically the same as for the No. 585 under the same conditions.

It was assumed, therefore, that the value of n obtained represented the values of x_c actually existing in the cylinders, and that the steam consumption of the No. 929 for the steam actually used in the cylinders was the same as for the No. 585.

The average steam consumption of No. 929 was 23.8 lb. per i. h. p. hr., while that of No. 585 for the tests run at the same speeds was 19.9 lb., showing that No. 929 consumed 19.6% more steam than did the No. 585 for the same conditions.

The average quality of x_c in the high pressure cylinders of the No. 929 was found to be 0.836, as computed from the values of n, S, and R, using the equation given on page 29. In a similar manner the value of x_c for the low pressure cylinders was found to be 0.817, making the average value of x_c for both the high and low pressure cylinders, 0.827.

The average apparent value of x_c from the tests for both high and low pressure cylinders was 0.674. Since this value of x_c is lower than 0.827, more steam to the amount $\frac{0.827—0.674}{0.827} = 18.5\%$ was used than was accounted for in the cylinders.

The results of these computations is a striking proof that not only was large valve leakage taking place, but that its amount has been established by two independent methods, which corroborate each other to a marked degree of accuracy. No. 929 consumed 19.6% more steam than the No. 585, while from the relations of x_c and n it is seen that 18.5% more steam was used than that which was accounted for in the cylinders. This analysis shows conclusively why the No. 929 had such poor economy in steam consumption when compared with all the other compound locomotives tested.

An examination of the design of the valves in No. 929 was made to ascertain if there were any peculiar features present in these valves which would account for the large valve leakage. The design is shown in cross-section in the report of the St. Louis tests, page 390. It will be seen that there are two annular passages containing live steam from which the high pressure cylinder receives its supply. The high pressure valve is in effect two inside admission piston valves made in one and it is seen that the live steam has four possible avenues of leakage into the receiver as against only two in the ordinary piston valve. These four faces of the valve undoubtedly permit at least twice the leakage which occurs through an ordinary piston valve with only two faces, and they are doubtless responsible for the enormous valve leakage which has been shown to exist. The low pressure valve is an outside admission piston valve, having only two faces which would permit of leakage. The results show, however, that it leaked to about the same degree as the high pressure valve, so that its surface on the valve bushing must not have been in good condition or the piston rings were not yet worn to a good bearing.

The only other locomotive which had valves similar in design to those on the high pressure cylinders of No. 929 were the low pressure cylinders of No. 535, shown on page 540 of the report of the St. Louis tests. This locomotive has one valve which controls the steam distribution to both the high and low pressure cylinders. The portion of the valve serving the high pressure cylinder is in effect a simple inside admission piston valve, and as seen in Fig. 8 and 9 no unusual amount of leakage was present in the high pressure portion of the valve. The portion of the valve serving the low pressure cylinder is in effect two outside admission piston valves with four faces subject to leakage from steam in the receiver direct to the two annular exhaust passages. The values of x_c and n from the low pressure cylinders show the effects of very bad valve leakage at 80 r. p. m., becoming less in proportion at 160 r. p. m. and negligible at 240 r. p. m. The effects of the large valve leakage at 80 r. p. m. are also apparent in the increased steam consumption[1] of No. 535 over that obtained in the other compound locomotives. At 160 r. p. m. the effects of leakage begin to grow proportionately much less and at this and higher speeds the steam consumption decreased to the amount generally consumed by compound locomotives having their valves in good condition.

The valve leakage found for No. 929 is corroborated by the actual performance on the road of the class of locomotives to which No. 929 belongs. It was learned from an independent source that when one of these locomotives is starting a full tonnage train, the "blow," or leakage through the valves, is so great that a distinctive and continuous roar of leaking steam is heard.

The analysis which has been given for the low points in Fig. 8 and 11 shows that the variations in the vertical distance of the center of tests for each locomotive from the average line is almost certainly due to the fact that the valves of each locomotive have their own rate of leakage, the leakage for some valves being less than the average, while that of others is greater.

The amount of valve leakage existing for a particular locomotive probably depends on the design and relative size of the valves, and also on the condition of the surfaces of the valve seats, balance rings, and balance plates for slide valves, and of the surfaces of the valve bushings and piston rings for piston valves.

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[1] Locomotive Tests and Exhibits, pp. 707, 708, 710.

Referring to Fig. 3 the relatively high point of the Purdue locomotive and its flat speed effect curve in Fig. 4 probably means that its valves were tighter than any of the others, due to its being kept in laboratory condition. On the other hand, the low point of No. 1499 in Fig. 3 and its steep speed effect curve in Fig. 5 is probably due to the fact that this locomotive was new and had not been broken in before it was tested, consequently the valves had not worn to a good surface, and the average leakage was larger than that for any of the other simple locomotives tested.

29. *Values of x_c.*—The assumption has been made throughout this investigation that the steam saved in the cylinders in compression was always dry saturated at the beginning of compression and the values of x_c given were computed on this basis.

It is probable, however, in the simple locomotives, that the compression steam is slightly wet for engines using saturated steam and is superheated for engines using highly superheated steam.

If these two conditions exist the values of x_c as given are slightly wrong. Any error from this cause does not affect the results, however, if the convention of dry steam at compression is uniformly followed. The values of x_c obtained by following this convention are comparable though not absolutely correct.

30. *Values of x_c and n Found for Various Types of Locomotives—Their Use in Design.*—Fig. 3, 8, and 11 show the average values of x_c and n which are obtained from typical simple and compound locomotives. Where conventional indicator diagrams are laid out before the locomotive is built, the data show the values of n which should be used for the expansion curves. The value of $n=1.0$ still may be used for the compression curves without serious errors.

The value of n for the expansion curves of locomotives using steam superheated 250° F. should be assumed as an average value of 1.3.

V. Directions for Determining the Steam Consumption of Locomotive Engines from the Indicator Diagrams

31. *Preparation of Indicator Diagrams for the Application of the n—x_c Method for Determining Steam Consumption.*—Possibly 95% of the locomotives in use in the United States and Canada are of the type using simple cylinders. The compound locomotive, with the single

exception of the Mallet type, has dwindled in numbers and importance since the introduction of the high superheat simple locomotive.

The directions for applying the $n - x_c$ method will therefore be outlined in full for the simple type, and the change in the method for its application to the compound type will be briefly mentioned.

Since the $n - x_c$ method depends entirely on the indicator diagram, great care must be observed in taking these diagrams. The indicator itself must be an accurate instrument in the best possible condition. The indicator pipe connections must be large, short, direct, and well covered with heat insulating material. An extensive investigation by Dr. W. F. M. Goss[1] shows that long and indirect pipe connections materially alter the form and character of the expansion curves. A theoretically correct reducing motion, free from lost motion, must be used so as to reproduce the actual expansion. Very short cords for the indicator drum must be used to avoid cord stretch. The arrangement of having one indicator at each end of the cylinder is always to be preferred if the road clearances allow it.

It is to be remembered that the method accounts for the actual weight of steam and water present in one revolution only, as represented by the set of diagrams analyzed.

Since the method accounts for the consumption on the basis of one revolution, indicator diagrams for road tests must be taken at regular intervals of distance, perhaps ½ or 1 mile apart. The mile post can be used to indicate the time for taking diagrams. The rate of speed must be observed as each set of diagrams is taken, as the speed has an influence on the relations of x_c and n.

After the test is over all diagrams are integrated and the average horsepower obtained in the usual manner. To apply the $n - x_c$ method the diagrams are divided into groups of similar lengths of cut-off, four or more groups generally being sufficient for this purpose. Since the effect of speed on the $n - x_c$ relations is a linear one, the average speeds may be used without error. From each group as outlined above select two sets of diagrams, each taken at the same reading, which are nearest in area to the average area of the group and which also are nearest to the average speed which prevailed for the diagrams in the group.

Construct logarithmic diagrams for each set as described in detail in Appendix I. From these diagrams the average value of n for one set of diagrams is determined.

[1] Trans. Am. Society of M. E., Vol. 17, p. 398.

The relations of x_c, n, and S for simple locomotives are plotted in the chart of Fig. 13. The values of n and S are located on the chart and the intersection of the lines representing them is located. The intersection is then seen to lie between two lines of constant quality, or value of x_c, the exact value of x_c being determined by interpolation. The value of x_c found gives the quality of the steam mixture at cut-off. From the steam accounted for per revolution at cut-off by the indicator, and the value of x_c found for this steam, the actual weight of steam and water in the cylinder is determined. The weight of dry steam saved per revolution in compression is determined as described in Appendix I. The total weight of steam and water per revolution found to be present, less the weight of compression steam saved per revolution, gives the weight of steam supplied per revolution by the boiler for average conditons of valve leakage. Calculations similar to those described but in the reverse order are given in detail in Appendix I. Similar calculations are also given in Bulletin 58.

After all the sets chosen are analyzed the average consumption at different values of cut-off is determined on the basis of consumption in one revolution.

To determine the water consumed by the engine over a given run or during a given time, the average steam consumption per revolution for each group is multiplied, first by the number of sets of diagrams in any one group of the different cut-off values, and second by the number of revolutions that the drivers have made between the taking of cards. In this manner, if diagrams are taken every mile, and the number of revolutions made by an 80 inch driver would be 252, the calculation described gives the total water consumed by one group. The consumption for the other groups, after being computed in the same manner, are all added and the total water used for the period is obtained.

Instantaneous rates of consumption in total weight of steam per hour or per indicated horse power hour can be obtained from each set of diagrams taken.

32. *Other Applications of the* $n — x_c$ *Method.*—If it is desired to test an engine for valve leakage, the locomotive should be tested on a test plant or under road conditions where the steam used for other purposes is known. The steam used by the engines is accounted for by the $n — x_c$ method, the total water fed to the boiler is measured, and this includes the amount used in the cylinders; the amount that leaked through the valves over the average leakage of the valves when in good condition is accounted for by the difference between the two measurements if the boiler is tight.

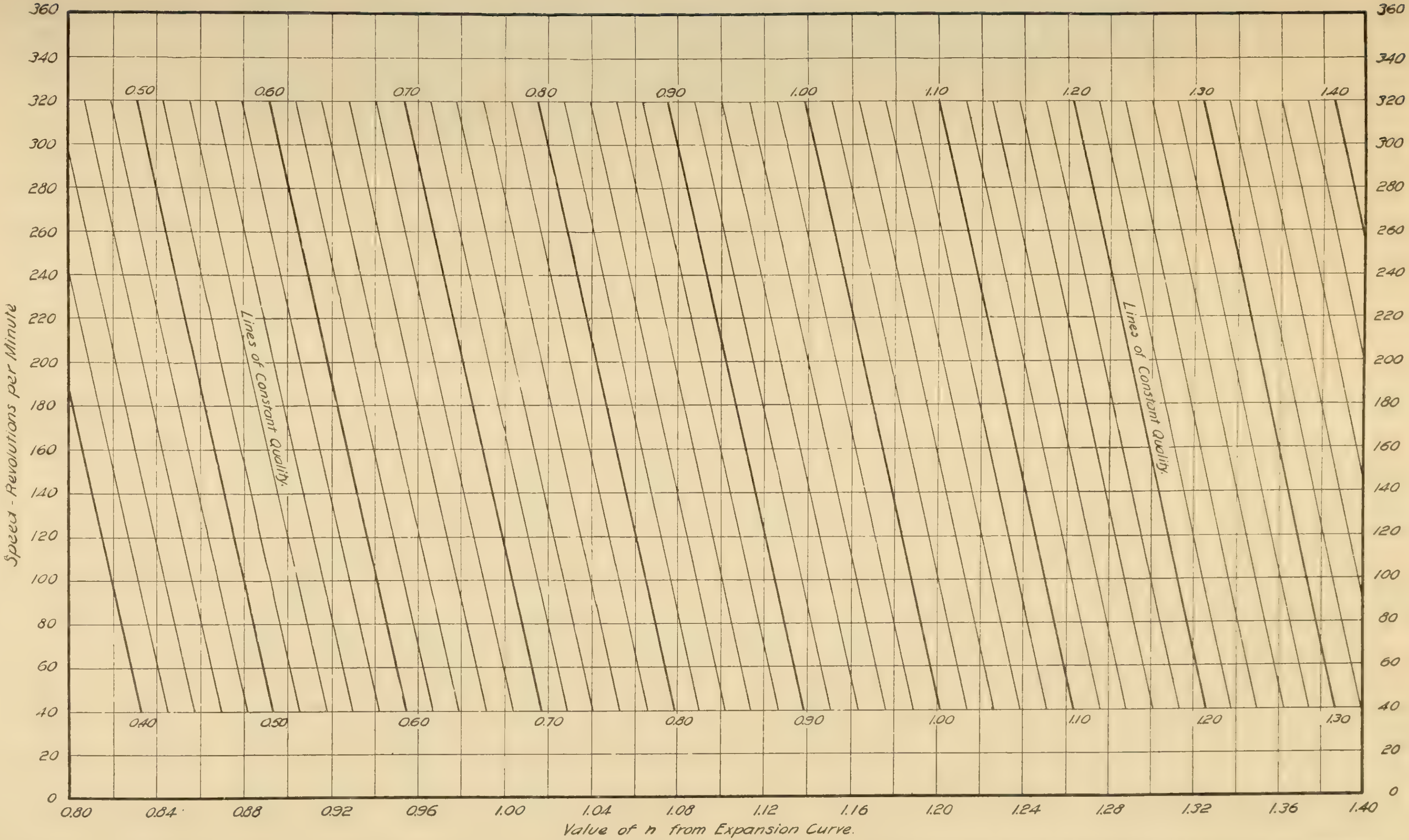

FIG. 13. THE RELATION BETWEEN SPEED AND THE VALUE OF n FOR SIMPLE LOCOMOTIVES WITH CONSTANT QUALITY OF STEAM IN THE CYLINDER AT CUT-OFF.

Locomotives in winter passenger service use such a large proportion of the steam generated by the boiler in heating the train, running the air pump, etc., that in combination with the increased train resistance in cold weather, schedules are maintained with great difficulty. It is practically impossible to measure the steam used in this way by any methods heretofore employed.

The $n - x_c$ method may be employed for this purpose by accounting for the difference between the total water fed to the boiler and that used by the engines. The difference is that which is used to heat the train, to operate the air-pump, head-light sets, train-lighting sets, blower and also that steam and water which is lost through the safety valves, blow-off valves, and boiler leaks. The $n - x_c$ method provides the only means believed to exist by which these uses of steam for auxiliaries or that which is lost may be measured.

33. *Application of the $n - x_c$ Method to Compound Locomotive Engines.*—The application of the $n - x_c$ method to compound locomotive engines differs from the method of application to simple locomotive engines only in detail, because of the difference in construction.

The total steam used by the engines may be obtained from either the high pressure or low pressure diagrams, as the same steam is used by both cylinders. If only the total steam used by the engines is desired, and not the quantity per indicated horse power hour, then the low pressure diagrams are all that are required.

It is possible to take both the high and low pressure diagrams without difficulty when all the cylinders are located outside of the frames, but it is generally difficult to take diagrams from inside cylinders.

The low pressure diagrams are better for the application of the $n - x_c$ method than the high pressure diagrams, because of the relative smoothness of the expansion curves from the low pressure cylinders. Of course the method may be applied to both cylinders, the determinations then serving as a check on each other.

One additional important variable must be considered in compound diagrams, namely the range of pressure from cut-off to the back pressure.

The method can be applied to Mallet locomotives by applying the regular high and low pressure relations of x_c and n. Either or both the high pressure and low pressure diagrams may be used.

The relations of x_c, n, S, and R for high pressure cylinders are given for compound engines on page 27, and for low pressure cylinders on page 29.

34. *The Degree of Accuracy Obtained by the Use of the $n - x_c$ Method.*—The steam consumption of all of the 185 tests of the six simple locomotives examined may be recomputed from the relations of x_c and n to an average difference of 3.7% from the test results.

In the tests of the compound locomotives, the average difference for the high pressure tests is about 8%, and for the low pressure tests 3.8%.

It is extremely probable that at least one fourth of the per cent. difference given is due to irregularities in measuring the difference in the height of the water in the boiler gage glass at the start and at the finish of the test. It must be remembered that all of the boiler tests were only ½ to 3 hours in length, so that an error in the gage glass correction means a noticeable difference in the water actually evaporated.

If one fourth of the difference is credited to errors of the boiler measurements then the average differences are 2.8%, 6% and 2.9% for the simple cylinders, the high pressure, and low pressure cylinders respectively. These differences show that the $n - x_c$ method is close enough for all the purposes of locomotive tests. The high difference of the high pressure cylinders is due to the difficulty of obtaining good values of n because of inertia in the expansion curves, and also to variable valve leakage.

VI. Application of the Logarithmic Method to the Determination of the Leakage, Clearance, and Location of Cyclic Events in Locomotive Tests

The methods which have been developed from the logarithmic diagram for detecting leakage into or out from the cylinder, for determining the clearance, and for closely locating the events of the cycle, such as cut-off, lead, etc., have been fully described in Bulletin 58 of the Engineering Experiment Station.[1] The reader is referred to the previous work for the methods employed.

35. *Uses of the Method for Detecting Leakage.*—The method of detecting leakage from the logarithmic diagram may be employed in locomotive tests to detect piston "blows," and valve leaks either into or out from the cylinder. In some cases it is possible to compute the amount of steam which leaked.

36. *Uses of the Method for Determining Clearance.*—If the clearance of a locomotive cylinder be desired, it may be determined from the logarithmic diagram to within 5% to 10% of the actual clearance volume.

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[1] Also in Journal A. S. M. E. April, 1912.

37. *Uses of the Method for Closely Locating the Cyclic Events.*—It has been generally known that the valve gears of locomotives give a later cut-off at high speed than at low speed with the reverse lever in the same notch. This is due to the spring or lag caused by the lost motion of worn parts and to inertia. The Stephenson valve gear is the worst offender in valve gear spring due to the indirect motion which is necessary.

The most accurate method of measuring the amount of this spring in use at present is to take valve ellipse diagrams from the valve rod. Experiments using this method have been carried on by the University of Illinois. The Pennsylvania Railroad System has attempted to measure the amount of this spring from the difference of cut-off as shown by the indicator diagrams for high and low speeds with the reverse lever in the same notch.

To show the amount of the spring of valve gears the following is quoted from Bulletin No. 5, Pennsylvania Railroad System, Tests of an E2a Locomotive, No. 5266. The tests of this same locomotive are included in this investigation.

"It is apparent that tests at different speeds, while run with the reverse lever in the same notch, do not have the same actual cut-off in the cylinders, but the cut-off point becomes later as the speed increases, due, probably, to a springing of the valve motion. This effect is so marked that the locomotive will run forward at the higher speeds with the reverse lever in one of the notches of the backward motion. The cut-off increases from 15.7% at 80 r. p. m. to 21.4% at 320 r. p. m., while the nominal cut-off or reverse lever notch remains the same."

The extremely close location of the cyclic events, cut-off, release, the beginning of compression, and lead obtainable from the logarithmic diagram enables the study of the spring of valve gears to be carried on with only the indicator diagrams taken at various speeds with the same reverse lever position.

VII. Conclusions

The data support the following conclusions:

(1) The actual steam consumption of simple locomotive engines in regular service on the road, when the valves are in good condition, may be determined from the indicator diagrams alone to within an average difference of from 3 to 4 per cent. of the consumption as measured on test plants.

(2) The actual steam consumption of compound locomotive engines in regular service on the road, when the valves are in good con-

dition, may be determined from the low pressure indicator diagrams alone to within an average difference of from 3 to 4 per cent. of the consumption as measured on test plants. It also may be determined from the high pressure diagrams to within an average difference of 6% from the test results.

(3) The weight of steam lost by valve leakage in excess of that usual for valves in good condition may be determined by accounting for the difference between the steam used by the cylinders as shown by the $n — x_c$ method and the water fed to the boiler if the boiler is tight and if steam is used for no other purpose than operating the engines.

(4) The weight of steam used for other purposes than operating the engines may be determined in road tests, when the valves are in good condition, by accounting for the difference between the steam used by the cylinders as shown by the $n—x_c$ method and the water fed to the boiler.

APPENDIX I

THE LOGARITHMIC DIAGRAM

1. *Description of Logarithmic Cross-section Paper.*—Logarithmic cross-section paper differs from rectangular cross-section paper in that the distances from the origin are proportional to the logarithms of the numbers to be plotted instead of the numbers themselves. This system of co-ordinates gives an uneven scale similar to that on a slide rule.

The numbers of the divisions on logarithmic paper are placed opposite the lines corresponding to their logarithms, as on a slide rule, instead of the values of the logarithms of the numbers. This fact aids in plotting, as the logarithms are employed without having to ascertain their values.

The logarithmic cross-section paper used in this investigation consists of four squares arranged two each way. These squares are five inches each way, making the four squares together ten inches each way. The use of four squares enables values to be plotted ranging from 0.1 to 10.0, 1.0 to 100.0, etc., thus giving a range of ten times the values obtainable if only one square were used.

2. *Construction of the Logarithmic Diagrams.*—The co-ordinates of the indicator diagram are proportional to pressure and stroke, the latter being proportional to the volume displaced by the piston. The co-ordinates of several points on the indicator diagrams are found in terms of absolute pressures, preferably in pounds per square inch, and absolute volumes, preferably in cubic feet. The scale of units employed is not material as long as it starts at the line of zero pressure, or of zero volume. However, the units are more easily manipulated afterwards if they are the same as are used in the steam tables.

The method of transferring the indicator diagram to the logarithmic form is described in detail for the diagrams of Test 110 of the Purdue locomotive, given in Fig. 14*a*, Crank End. The diagram is shown in outline by *ABYX*. Perpendiculars *QR* and *EX* are drawn to the atmospheric line *EQ,* and pass through the extreme stroke positions of the diagram. The distance *EQ* is then the length of the diagram. *OM* is laid off perpendicular to the atmospheric line *EQ* (extended) which was drawn by the indicator pencil. *OM* is the line of zero volume, and is drawn at a distance *FE* from the admission end *EX* of the diagram, the distance *FE* being the same length in per cent. of the line *EQ,* or length of the diagram, as the proportion that the per cent. of clearance, or waste space, of the cylinder bears to the piston displacement. In this case the length of the diagram is 3.70 inches, and the clearance is 7.98%. The length *FE* is therefore 0.0798 x 3.70, or 2.95 inches. *ON* is the line of zero pressure and is drawn a distance *FO* below the atmospheric line, to the scale of the spring used in obtaining the *PV*-diagram. This distance is proportional to the barometer reading, corrected for temperature, prevailing at the day and place of the engine test. In this case the corrected barometer reading is 14.7 lb. per sq. in. absolute, so the distance *FO* is $\frac{14.7}{150.0}=0.098$ in.

From *ON* points are laid off on *QR* and *EX* corresponding to the absolute pressures at the intervals where it is desired to read off the corresponding volumes. Fine lines are drawn connecting similar pressure points, as 40–40, 60–60, etc. The volumes *G–A, F–B, H–D, G–C,* etc., are read off in hundredths of an inch to the nearest half hundredth. The tabular form used in this investigation is given in Table 3 for the diagrams of Fig. 14*a* taken in Test 110 of the Purdue locomotive. Thus the length *G–A* is read off as 1.20 inches, and is given under the column for 40 lb. pressure headed Comp., meaning the compression curve for the crank end diagram. The volumes in inches are then multiplied by the constant ratio which one inch of length of the diagram bears to the displacement of the piston. From Table 3 it is seen that the piston displacement of the crank end is 2.72 cu. ft., and the length of diagram 3.70 inches; hence, the ratio is $\frac{2.72}{3.70}$ or 0.735 cu. ft. of piston displacement per inch of diagram length. The length *G–A* in cu. ft. of displacement now becomes 1.20 in. x 0.735 cu. ft. per inch, the volume of steam present at this point. This process is repeated at intervals until the co-ordinates of from ten to thirty points are determined. In the diagram shown in Fig. 14*a* the co-ordinates of 27 points were found.

The co-ordinates of *P* and *V* are then plotted on logarithmic cross-section paper, as shown in Fig. 14*b,* which are the logarithmic diagrams derived from the indicator diagrams of Fig. 14*a*. The points plotted in Fig. 14*b* are taken from the columns headed cu. ft. at the pressures shown. A smooth curve is drawn through the points thus plotted, and the diagram is in shape to be studied.

It will be seen that the expansion curve becomes a straight line in the logarithmic diagram, as does also the compression curve. The value of *n,* which is the slope or measure of inclination of this line to the horizontal, is found as follows: in Fig. 14*b,* from a point *X* on the expansion line draw *OX* parallel to the axis of log. *P,* and draw *OY* parallel to the axis of log. V. The value of n is then the value of the ratio $\frac{OY}{OX}$.

3. *Method of Obtaining the Values of x_c and n from the Diagrams.* —The manner of computing the value of x_c and n is given for Test 110 of the Purdue locomotive, the representative indicator diagrams of which are given in Fig. 14*a*, and the logarithmic diagrams in Fig. 14*b*. The results of the computations for all tests are given in Tables 5 and 16.

The absolute pressure of cut-off was determined from both the indicator card and logarithmic diagrams by inspection for each end of both cylinders. The cut-off pressures from the four cards were averaged and this average was used to obtain the value of x_c for the test.

The logarithmic diagrams of Test 110 of the Purdue locomotive, shown in Fig. 14*b*, are the basis of the calculations for the value of x_c. The calculations which follow are given in detail in the same form as they were made for all tests.

COMPUTATIONS FOR THE VALUES OF x_c AND n FOR TEST 110 OF THE PURDUE LOCOMOTIVE

Volumes obtained from Fig. 14*b*.

Steam present at cut-off pressure of 138.0 lb. absolute.

Volume of steam present, right head end	0.666 cu. ft.
Volume of steam present, right crank end	0.603 cu. ft.
Volume of steam present, left head end	0.624 cu. ft.
Volume of steam present, left crank end	0.617 cu. ft.
Total, right and left sides	2.510 cu. ft.

Specific volume* of steam at 138.0 lb. absolute = 3.263 cu. ft. per lb.

Weight of steam present at cut-off $= \frac{2.510}{3.263} = 0.769$ lb.

Steam retained in compression at 15.0 lb. absolute.

Volume of steam present, right head end	2.470 cu. ft.
Volume of steam present, right crank end	1.893 cu. ft.
Volume of steam present, left head end	2.018 cu. ft.
Volume of steam present, left crank end	1.817 cu. ft.
Total, right and left sides	8.198 cu. ft.

Specific volume of steam at 16.0 lb. absolute = 24.79 cu. ft. per lb.

Weight of steam retained in compression $\frac{8.198}{24.79} = 0.331$ lb.

From Table 5 the weight of steam and water supplied = 6938 lb.

Revolutions per hour = 11670

Weight of steam and water supplied per revolution $= \frac{6938}{11670} = 0.5945$ lb.

---

* Marks and Davis Steam Tables.

Total weight of mixture present per revolution.

0.5945 lb. supplied
0.3310 lb. retained in compression
0.9255 lb. total present

$$x_c = \frac{0.769}{0.9255} = 0.831$$, or 83.1% of the total weight of mixture present as steam at cut-off.

Value of n from Fig. 14*b*.—

$$\text{Right head end } \frac{OX}{OY} = \frac{2.975}{3.055} = 0.974$$

$$\text{Right crank end } \frac{OX}{OY} = \frac{2.91}{2.775} = 1.048$$

$$\text{Left head end } \frac{OX}{OY} = \frac{2.875}{2.86} = 1.005$$

$$\text{Left crank end } \frac{OX}{OY} = \frac{2.975}{2.800} = \frac{1.062}{4.089}$$

$$\text{Average value of } n = \frac{4.089}{4.000} = 1.022$$

When the actual cut-off pressure was less than 138.0 lb. the line of constant weight of steam mixture on the logarithmic diagram was extended to this pressure, and the calculations made.

TABLE 3

Construction of the Logarithmic Diagrams of Test No. 110, of the Purdue Locomotive.†

No.	Absolute Pressure, Lb. sq. in.	Head End				Crank End			
		Volumes							
		Inches		Cu. ft.		Inches		Cu. ft.	
		Comp.	Exp.	Comp.	Exp.	Comp. X to P*	Exp. X to P*	Comp.	Exp.
1	230	0.34	0.31	0.263	0.240	.....	.....	.....	.....
2	220	0.35	0.27	0.271	0.209	.....	.....	.....	.....
3	210	0.365	0.32	0.283	0.248	0.325	0.30	0.239	0.221
4	200	0.38	0.41	0.294	0.317	0.335	0.38	0.246	0.278
5	190	0.40	0.54	0.310	0.418	0.345	0.48	0.254	0.353
6	170	0.425	0.68	0.329	0.526	0.38	0.65	0.279	0.478
7	150	0.455	0.795	0.352	0.615	0.405	0.76	0.298	0.559
8	140	0.465	0.845	0.360	0.654	0.42	0.81	0.309	0.596
9	130	0.49	0.91	0.379	0.704	0.45	0.87	0.331	0.639
10	120	0.53	0.99	0.416	0.766	0.48	0.93	0.353	0.684
11	100	0.655	1.20	0.507	0.929	0.56	1.125	0.412	0.827
12	80	0.795	1.495	0.615	1.157	0.68	1.36	0.500	1.000
13	60	1.00	2.06	0.774	1.594	0.855	1.815	0.628	1.334
14	40	1.44	3.07	1.115	2.376	1.20	2.69	0.882	1.977
15	30	1.83	3.33	1.417	2.577	1.55	3.18	1.139	2.337

	H. E.	Cr. E.
Length of indicator diagram	3.62 in.	3.70 in.
Ratio of clarance to Piston displacement (same end)	0.0744	0.0798
Length of diagram propotrional to clearance ratio	0.269 in.	0.295 in.
Piston displacement (cylinder 16″x24″)	2.802 cu. ft.	2.720 cu. ft.
Clearance volume	0.208 cu. ft.	0.217 cu. ft.
Ratio, cu. ft. per inch of length on diagram	0.774	0.735
Scale of indicator spring per in. of ordinate	150 lb.	150 lb.

*Letters refer to Fig. 14*a*, crank end. †Final results given in Table 5.

The point of compression was selected in the following manner from Fig. 14*b* for the reasons explained fully in Bulletin 58. The straight line of the compression curve in the logarithmic diagram, or the line of constant weight of steam mixture, was prolonged dotted to the back pressure as shown. The intersection of the compression line, prolonged, with the back pressure line, extended (in this test 16 lb.), was taken as the volume of dry steam retained in compression. This method generally gives less steam retained than the ordinary method.

Steam was found to be superheated at cut-off for practically all of the tests of No. 3395. The manner of measuring the value of x_c for superheated steam at cut-off was the same as for saturated steam; that is, the ratio of the volume of steam present at cut-off per lb. of the total weight of mixture present divided by the specific volume of dry saturated steam at cut-off pressure. To illustrate, it will be assumed that a quality of 1.25 is found for a test having a cut-off pressure of 160 lb. absolute. The specific volume of dry saturated steam at this pressure is 2.834 cu. ft. per lb. The value of x_c of 1.25 means that the specific volume per lb. of the total weight present was found to be 3.542 cu. ft. per lb. On examining the superheat portion of the steam tables, it is seen that the specific volume of 3.542 cu. ft. per lb. at 160 lb. absolute corresponds to steam at 152° superheat.

The value of x_c is based on the specific volume of dry saturated steam because the qualities obtained when the steam is superheated at cut-off are of the same order of magnitude as the qualities for wet steam, hence the curve does not "break" at a quality of 1.00.

4. *Typical Indicator and Logarithmic Diagrams from the Locomotives Tested.*—Typical indicator and logarithmic diagrams from the right side of each of the locomotives tested are given in Fig. 14-25. The figures of the indicator and logarithmic diagrams from the same locomotive are numbered the same but the letters *a* and *b* are used in addition to the figure number for the indicator and logarithmic diagrams respectively.

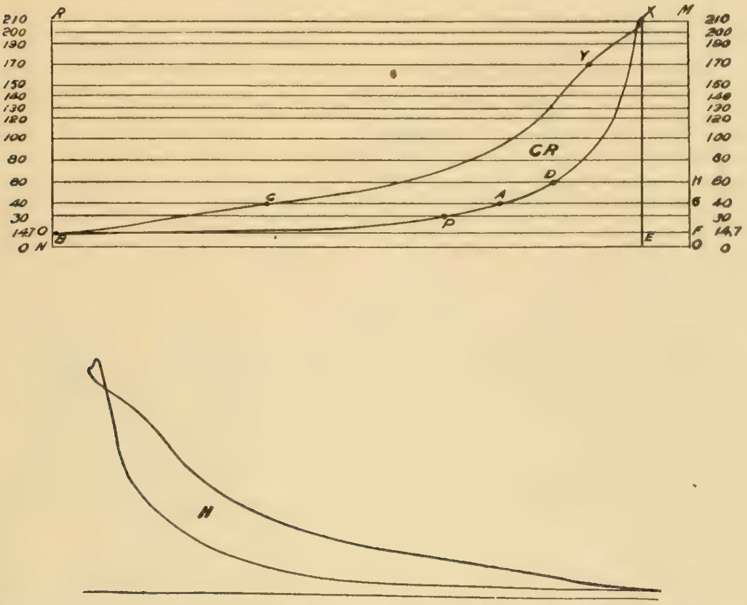

FIG. 14a. REPRESENTATIVE INDICATOR DIAGRAMS FROM THE PURDUE LOCOMOTIVE, TEST NO. 110.

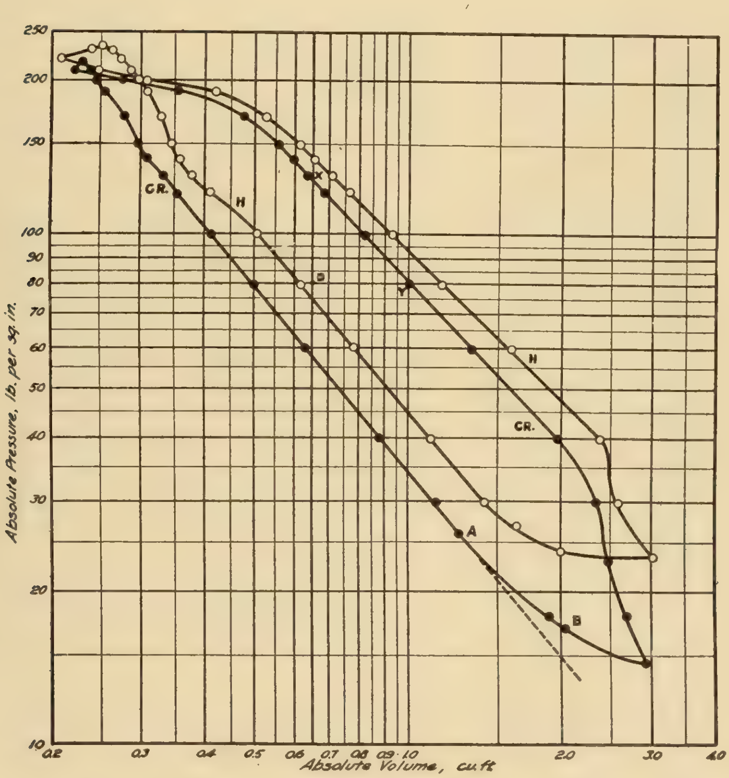

FIG. 14b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM PURDUE LOCOMOTIVE, TEST NO. 110.

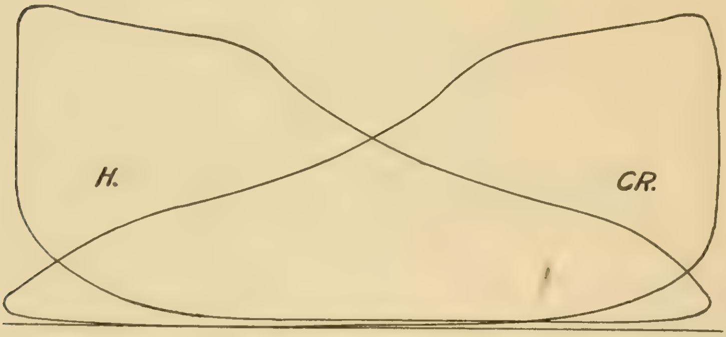

Fig. 15a. Representative Indicator Diagrams from Locomotive 1499, Test No. 118.

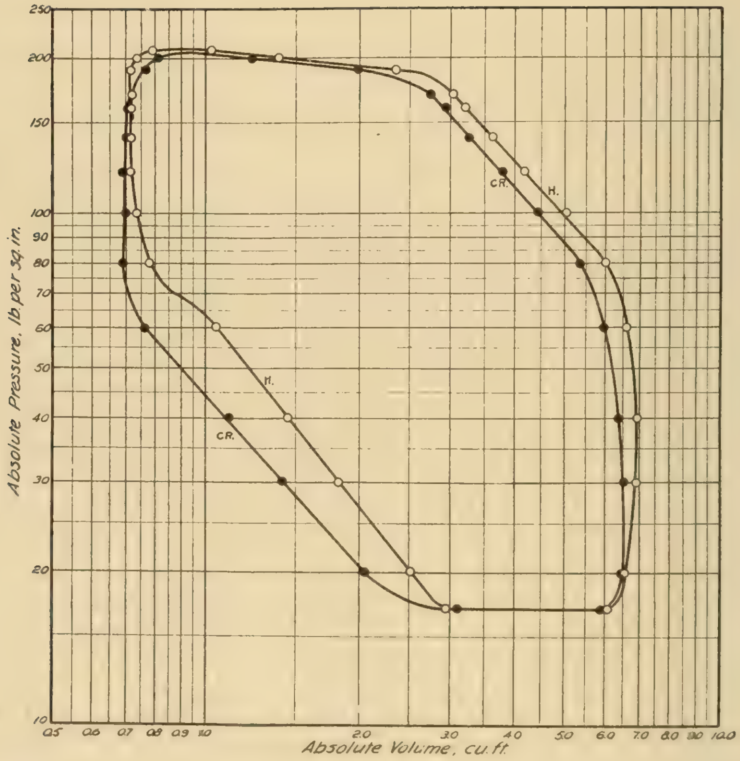

Fig. 15b. Representative Logarithmic Diagrams from Locomotive 1499, Test No. 118.

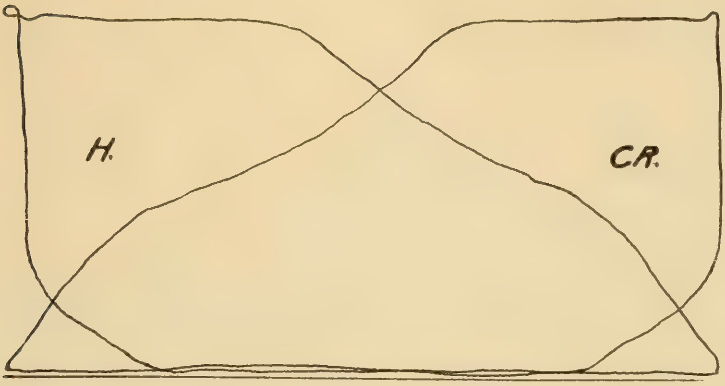

FIG. 16a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOCOMOTIVE 734, TEST NO. 203.

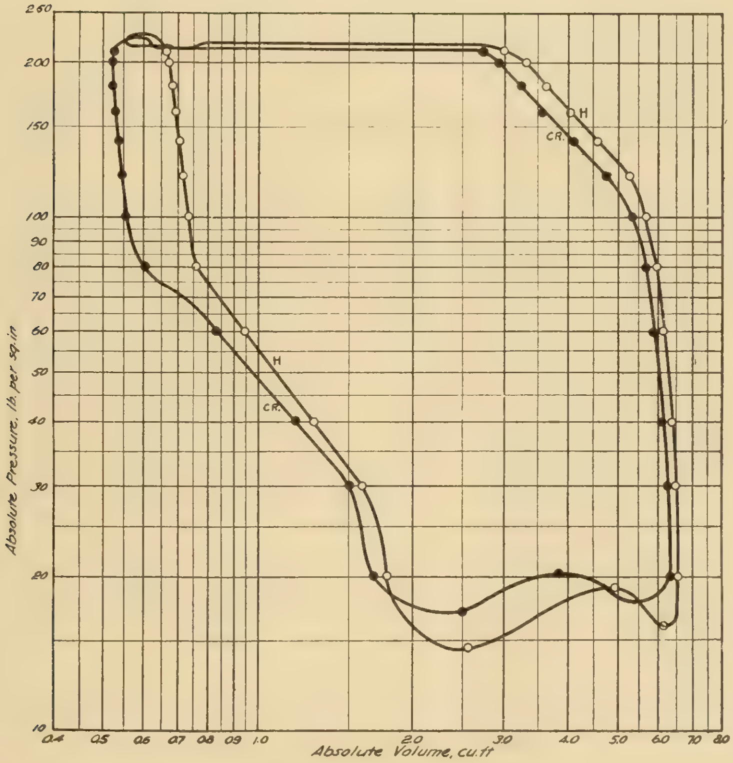

FIG. 16b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 734, TEST NO. 203.

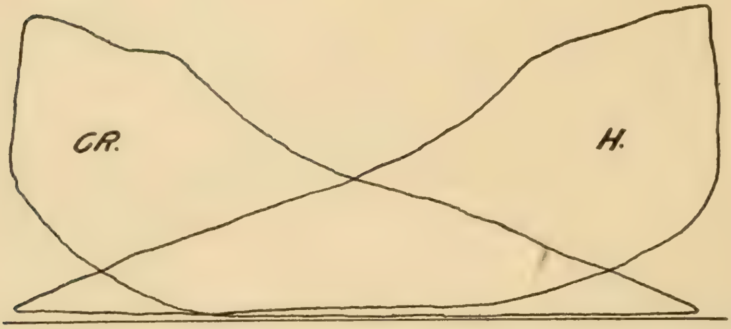

FIG. 17a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOCOMOTIVE 5266, TEST NO. 917.

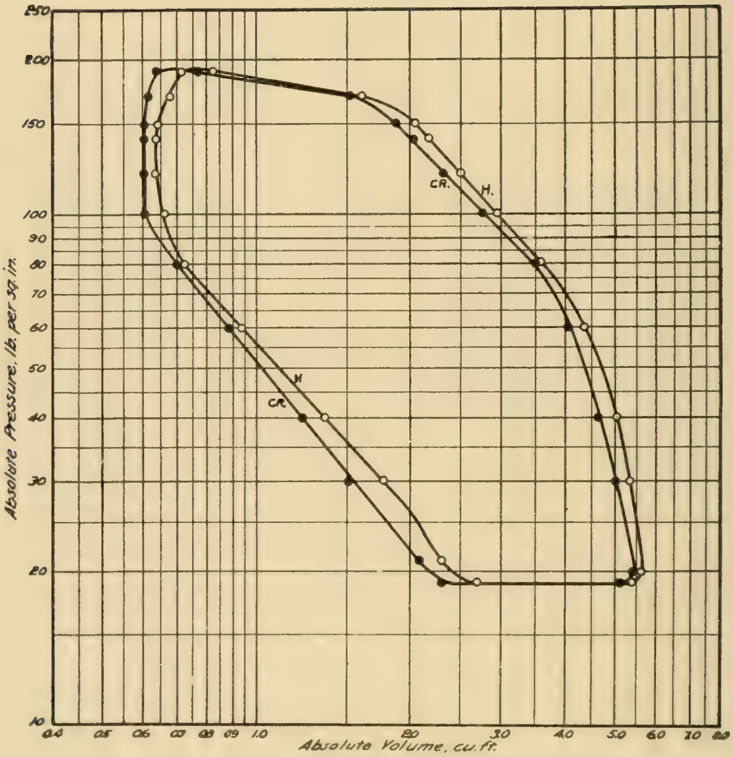

FIG. 17b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 5266, TEST NO. 917.

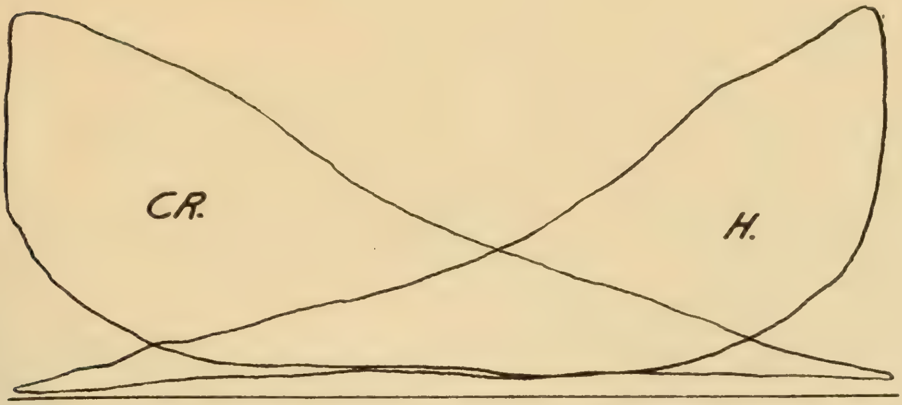

FIG. 18a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOCOMOTIVE 7510, TEST NO. 1613.

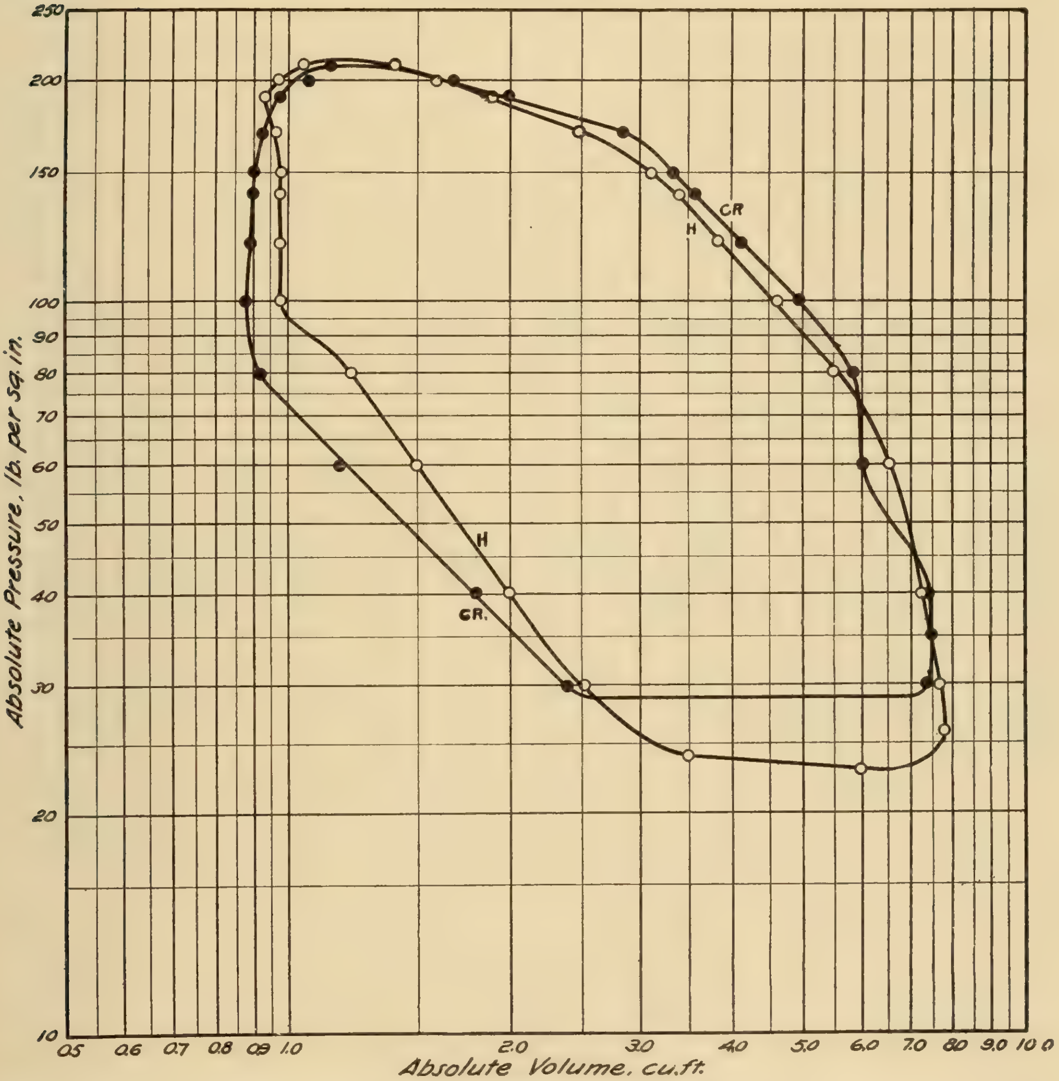

FIG. 18b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 7510, TEST NO. 1613.

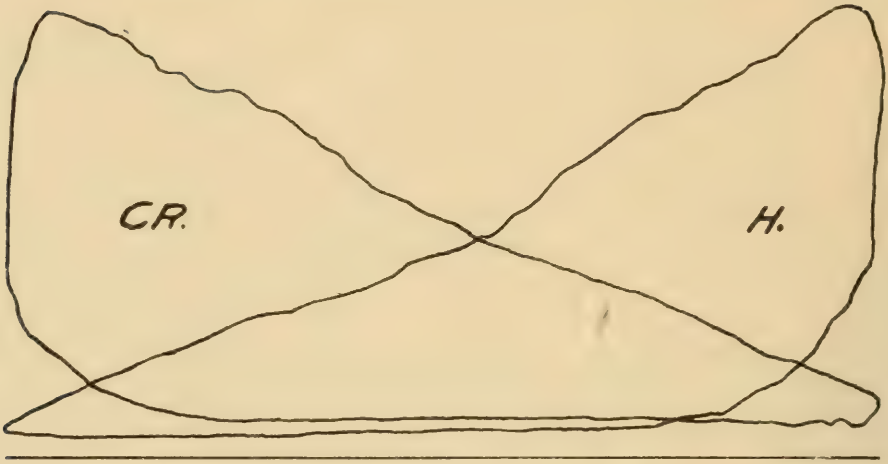

FIG. 19a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOCOMOTIVE 3395, TEST NO. 2413.

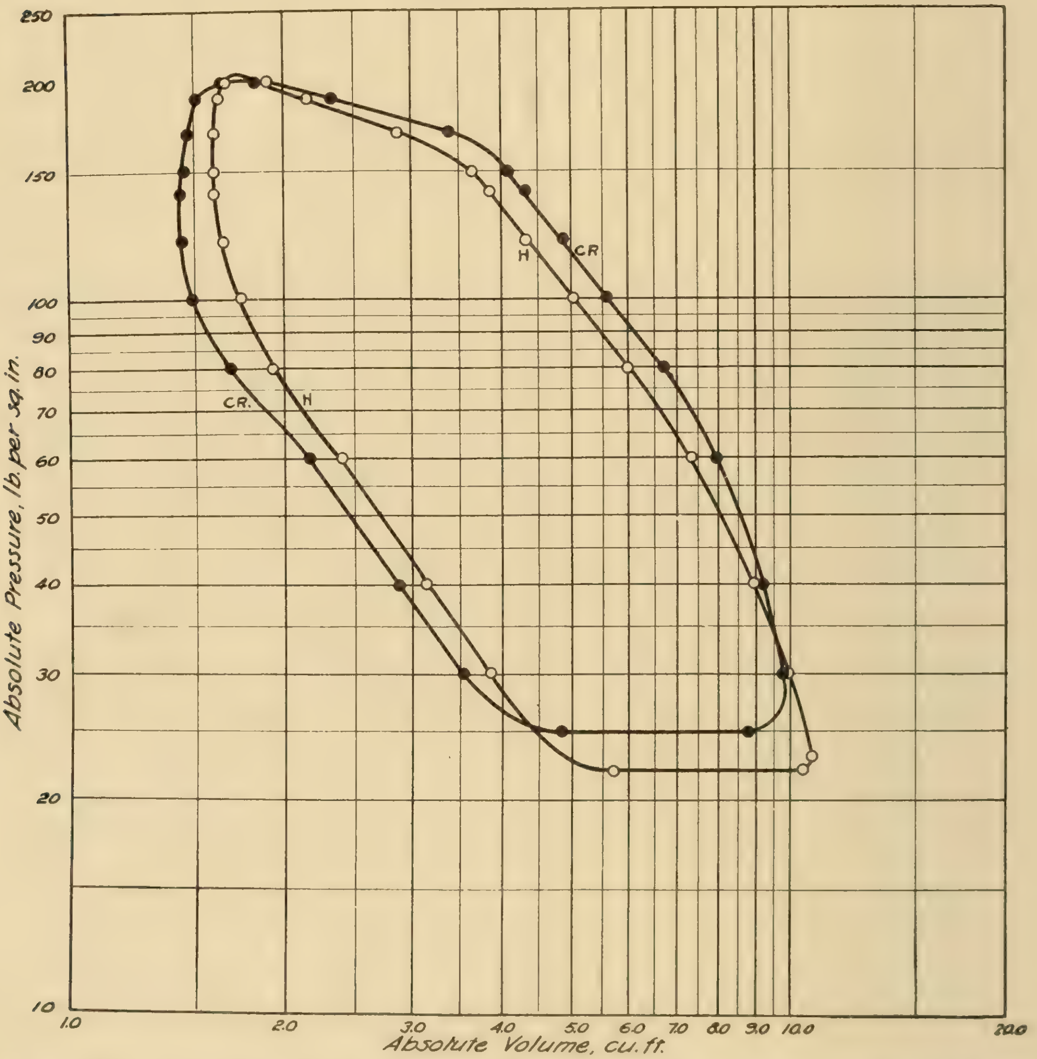

FIG. 19b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 3395 TEST NO. 2413.

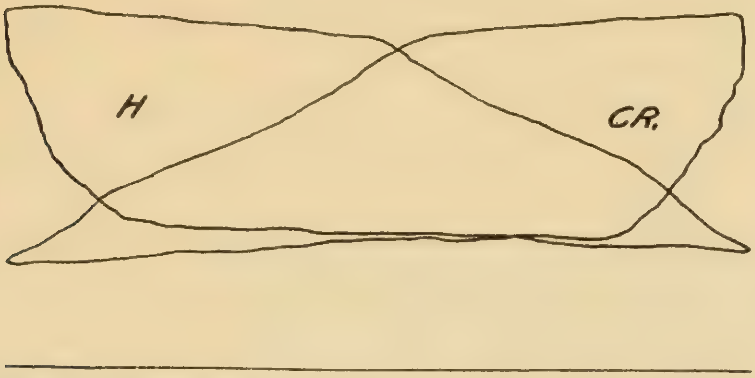

FIG. 20a. REPRESENTATIVE INDICATOR DIAGRAMS FROM HIGH PRESSURE CYLINDER OF LOCOMOTIVE 585, TEST NO. 308.

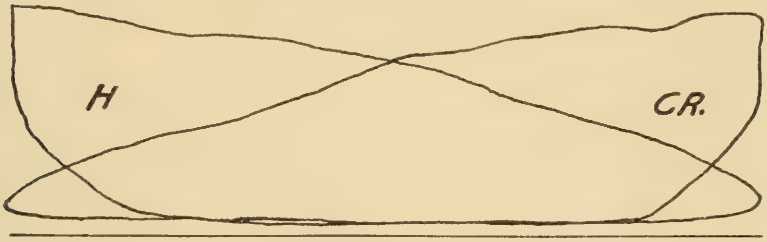

FIG. 20a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOW PRESSURE CYLINDER OF LOCOMOTIVE 585, TEST NO. 308.

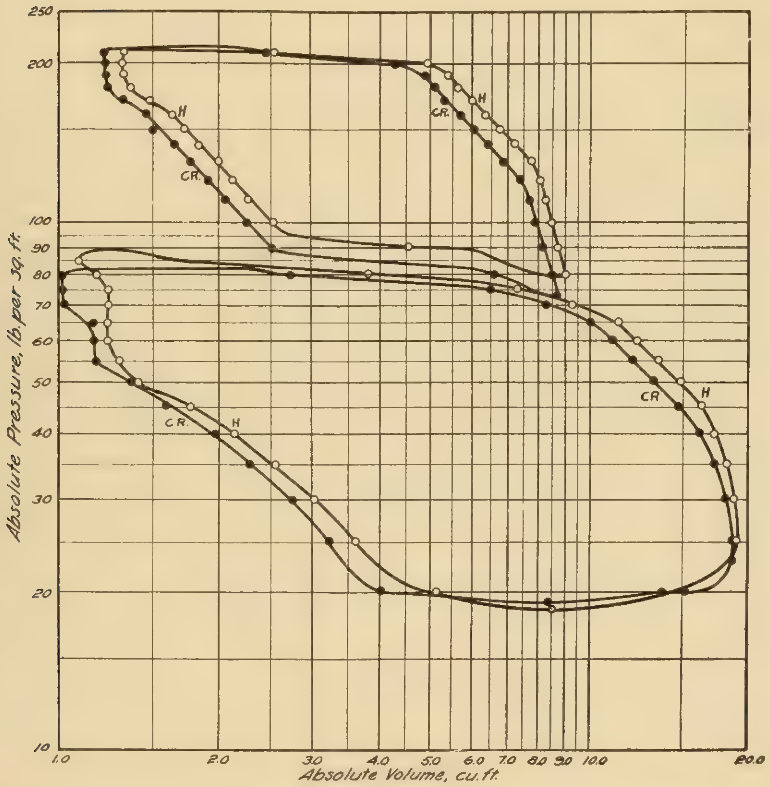

FIG. 20b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 585, TEST NO. 308.

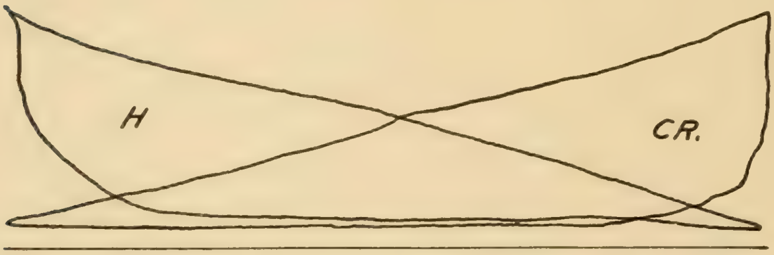

FIG. 21a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOW PRESSURE CYLINDER OF LOCOMOTIVE 929, TEST NO. 408.

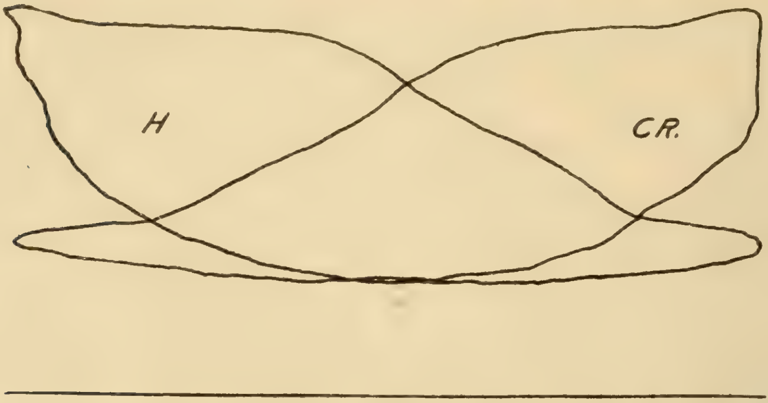

FIG. 21a. REPRESENTATIVE INDICATOR DIAGRAMS FROM HIGH PRESSURE CYLINDER OF LOCOMOTIVE 929, TEST NO. 408.

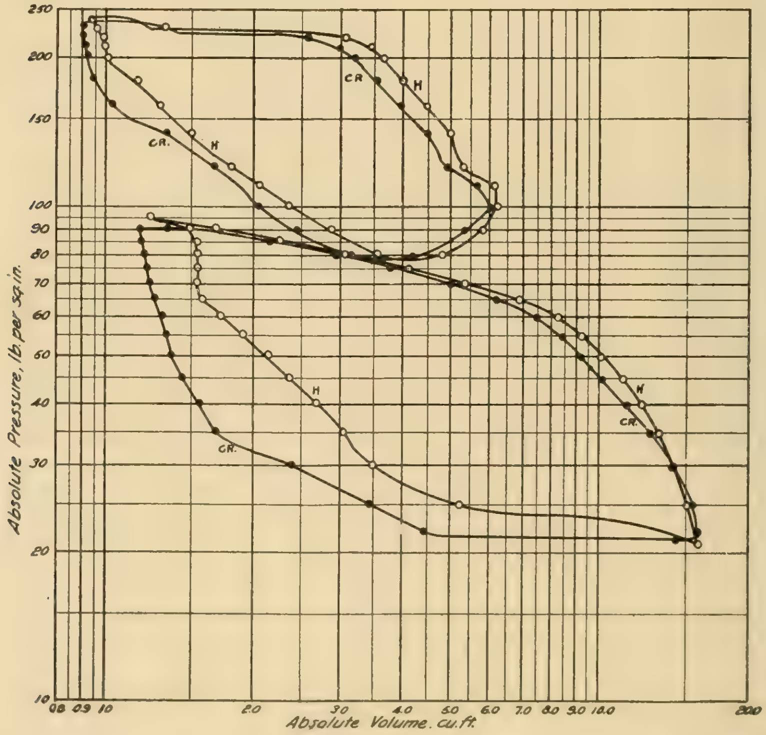

FIG. 21b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 929 TEST NO. 408.

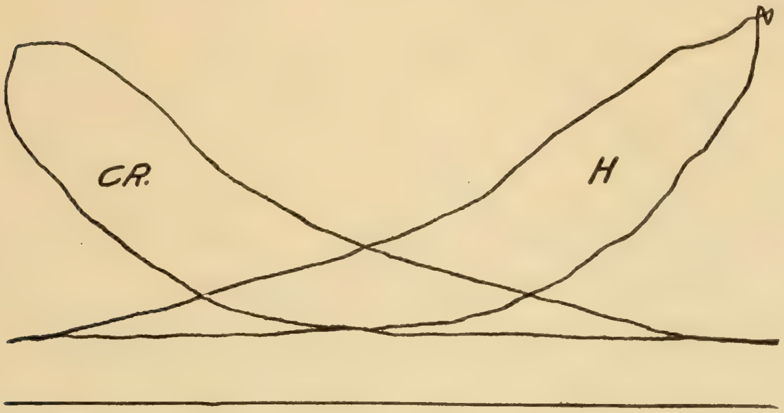

FIG. 22a. REPRESENTATIVE INDICATOR DIAGRAMS FROM HIGH PRESSURE CYLINDER OF LOCOMOTIVE 2512, TEST No. 510.

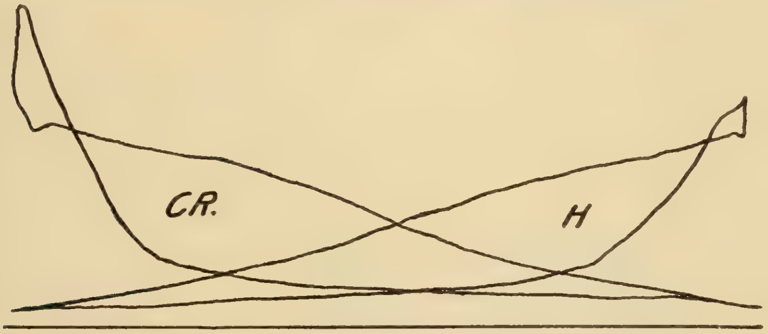

FIG. 22a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOW PRESSURE CYLINDER OF LOCOMOTIVE 2521, TEST No. 510.

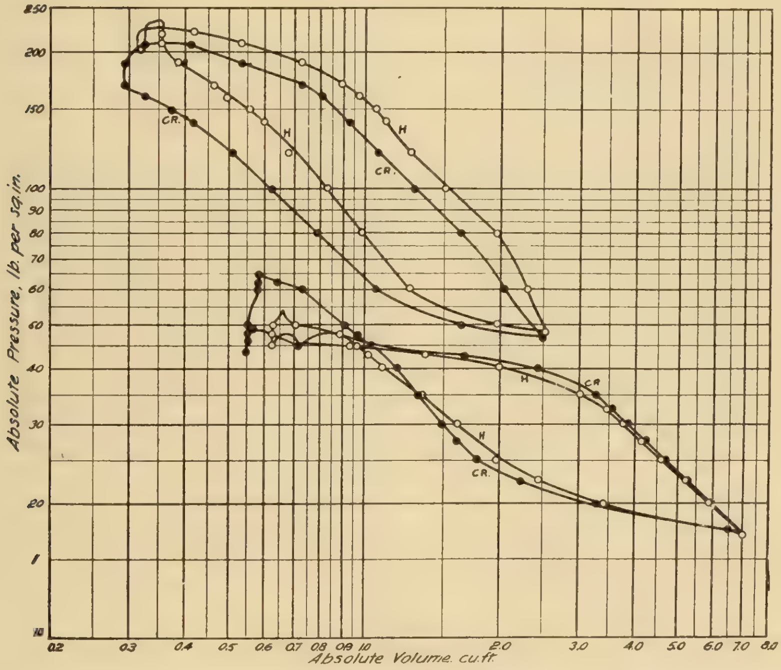

FIG. 22b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 2512, TEST No. 510.

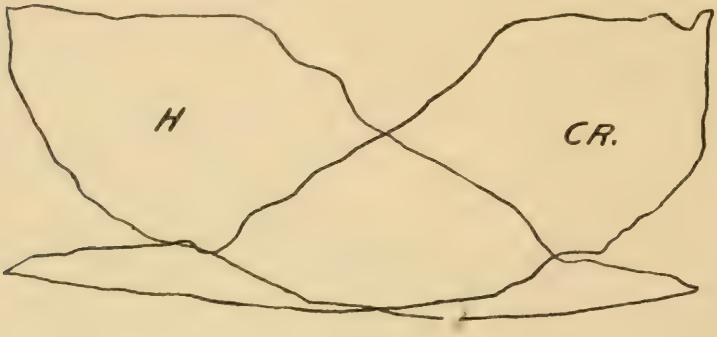

Fig. 23a. Representative Indicator Diagrams from High Pressure Cylinder of Locomotive 535, Test No. 603.

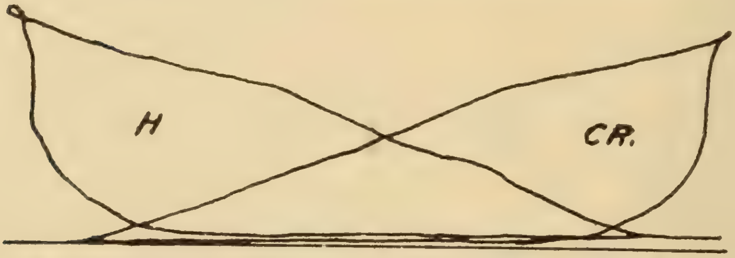

Fig. 23a. Representative Indicator Diagrams from Low Pressure Cylinder of Locomotive 535, Test No. 603.

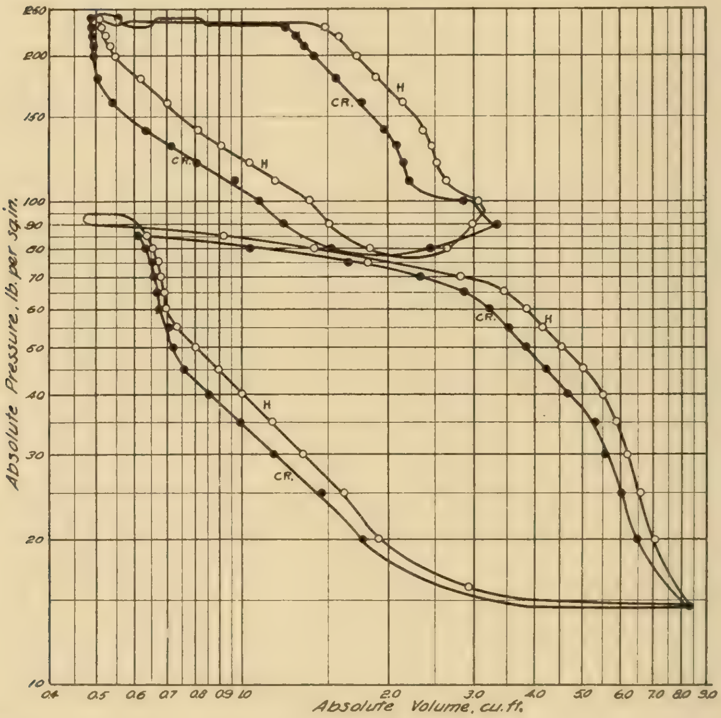

Fig. 23b. Representative Logarithmic Diagrams from Locomotive 535, Test No. 603.

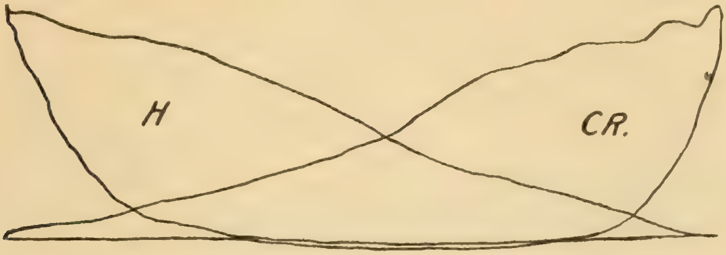

FIG. 24a. REPRESENTATIVE INDICATOR DIAGRAMS FROM HIGH PRESSURE CYLINDER OF LOCOMOTIVE 628, TEST NO. 711.

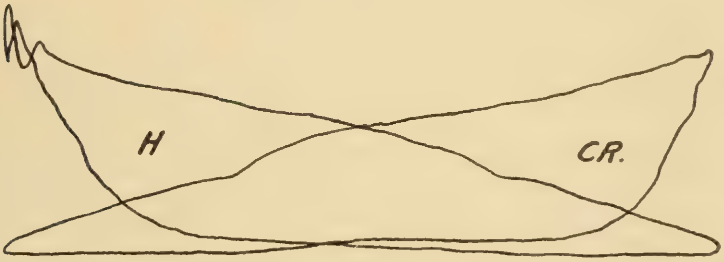

FIG. 24a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOW PRESSURE CYLINDER OF LOCOMOTIVE 628, TEST NO. 711.

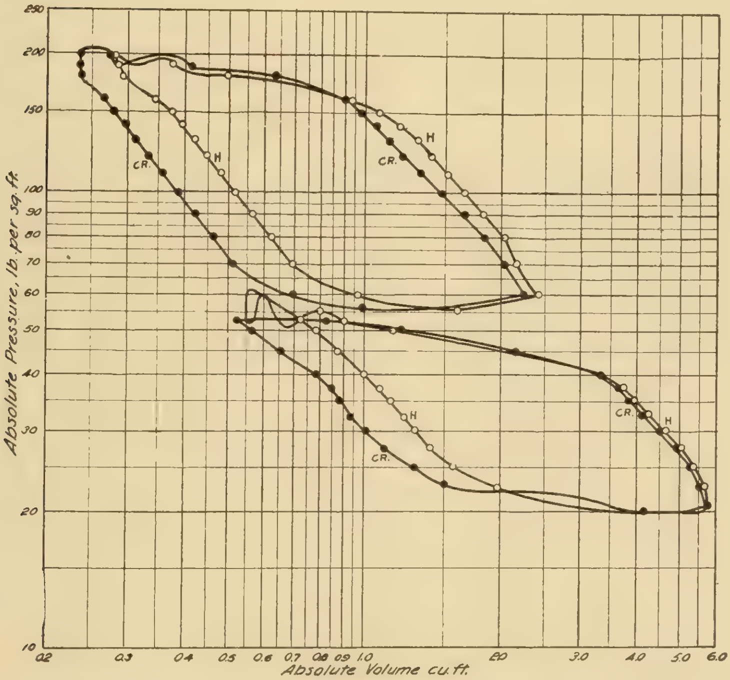

FIG. 24b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 628, TEST NO. 711.

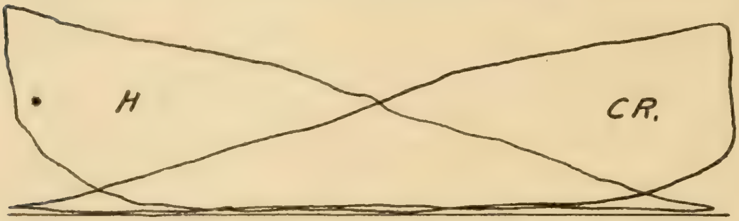

FIG. 25a. REPRESENTATIVE INDICATOR DIAGRAMS FROM LOW PRESSURE CYLINDER OF LOCOMOTIVE 3000, TEST NO. 802.

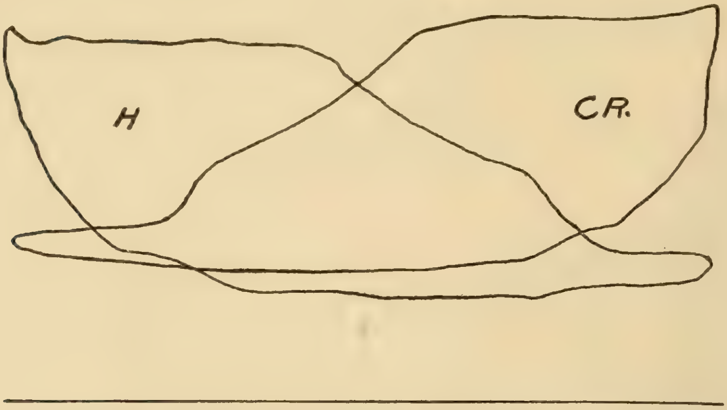

FIG. 25a. REPRESENTATIVE INDICATOR DIAGRAMS FROM HIGH PRESSURE CYLINDER OF LOCOMOTIVE 3000, TEST NO. 802.

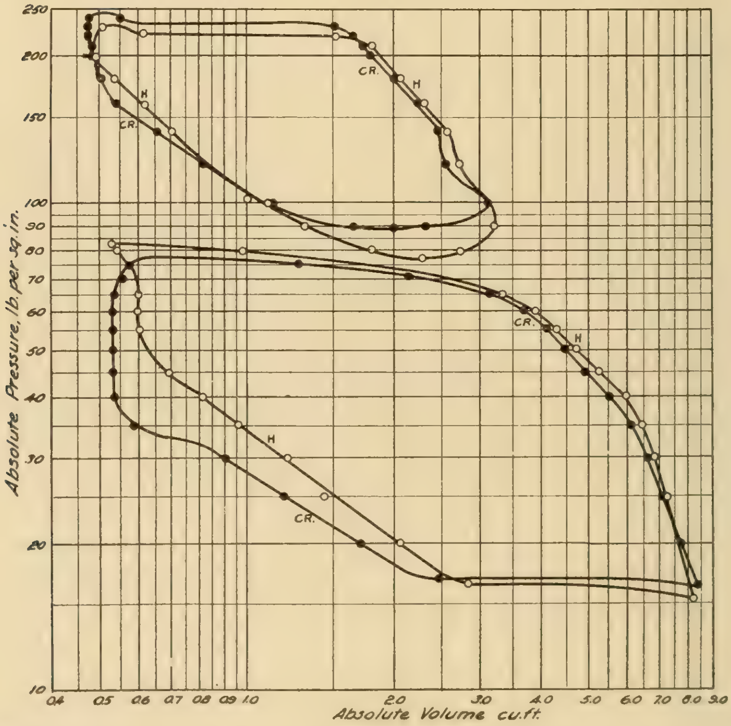

FIG. 25b. REPRESENTATIVE LOGARITHMIC DIAGRAMS FROM LOCOMOTIVE 3000, TEST NO. 802.

APPENDIX II

THE TESTS

1. *Principal Dimensions of the Locomotives Tested.*—The principal dimensions of the locomotives tested are given in Table 4.

2. *Logs of the Tests.*—The logs of the tests containing the quantities necessary for this investigation are given in Tables 5-16.

TABLE 4—PRINCIPAL DIMENSIONS

No. of Items*	Locomotive Number	Purdue #2	Purdue #3	1499	734	5266
	Type	American 8 wheels	American 8 wheels	Consolidation	Consolidation	Atlantic
	Class	Schenectady No. 2	Schenectady No. 3	H 6 a	B 1	E 2 a
	Owned by	Purdue University	Purdue University	P.R.R. Co.	L.S. & M.S R.R. Co.	P.R.R. Co.
	Tested at	La Fayette Indiana.	La Fayette Indiana.	St. Louis, Mo.	St. Louis, Mo.	Altoona, Pa.
	Driving Wheels					
1	Number of pairs	2	2	4	4	2
2	Approximate diameter, inches	70	70	56	63	80
	Engine Truck Wheels					
14	Number	4	4	2	2	4
15	Diameter, inches	69	69	29.78	36.68	36
	Trailing Wheels					
16	Diameter, inches	....	....	....	....	50
	Wheel Bases					
17	Driving wheel bases	8.5	8.5	16.550	17.342	7.42
18	Total wheel base	23.0	23.0	24.770	25.572	30.85
	Weight of Engine with Water at 2nd. Gage Cock and Normal Fire, in lb.					
20	On truck	48,000	48,000	21,000	18,700	37,167
21	On 1st. drivers	....	....	44,000	39,325	53,334
22	On 2nd. drivers	....	....	43,200	39,775	56,667
23	On 3rd. drivers	....	....	43,500	40,275	....
24	On 4th. drivers	....	....	42,500	43,225	....
25	On 5th. drivers	....	....	....	....	....
26	On trailers	....	....	....	....	37,000
27	Total	109,000	109,000	194,200	181,300	184,167
28	Total on drivers	61,000	61,000	173,200	162,600	110,001
	Cylinders					
29	High pressure, number	2	2	2	2	2
30	High pressure, number	....	....	....	....	....
31	Arrangement	Outside	Outside	Outside	Outside	Outside
	Diameter, inches					
32	High pressure, right	16.022	16.022	21.997	21.004	20.518
33	High pressure, left	16.160	16.160	21.993	21.023	20.812
34	Low pressure, right	....	....	....	....	....
35	Low pressure, left	....	....	....	....	....
	Stroke at Piston, Feet					
36	High pressure, right	2	2	2.332	2.499	2.164
37	High pressure, left	2	2	2.332	2.500	2.164
38	Low pressure, right	....	....	....	....	....
39	Low pressure, left	....	....	....	....	....
	Clearance Per cent of Piston Displacement					
40	H. P., right, head end	7.44	7.44	11.83	9.21	12.7
41	H. P., right, crank end	7.98	7.98	10.80	9.21	12.1
42	H. P., left, head end	7.34	7.34	11.31	9.26	12.4
43	H. P., left, crank end	7.63	7.63	11.25	9.36	11.9
44	L. P., right, head end	....	....	....	....	....
45	L. P., right, crank end	....	....	....	....	....
46	L. P., left, head end	....	....	....	....	....
47	L. P., left, crank end	....	....	....	....	....
	Receiver, Cubic Feet					
48	Volume, right side	....	....	....	....	....
49	Volume, left side	....	....	....	....	....
	Piston Rods, Diameter, inches					
74	High pressure, right	2.75	2.75	3.997	3.737	3.472
75	High pressure, left	2.75	2.75	3.998	3.733	3.501
76	Low pressure, right	....	....	....	....	....
77	Low pressure, left	....	....	....	....	....
	Tail Rods, Diameter, inches					
78	High pressure, right	....	....	....	....	....
79	High pressure, left	....	....	....	....	....
80	Low pressure, right	....	....	....	....	....
81	Low pressure, left	....	....	....	....	....

*Item numbers are the same as those given in the Reports of Tests at the St. Louis Exposition.

OF ALL LOCOMOTIVES TESTED.

7510	3395	585	929	2512	535	628	3000	No. of Items*
Pacific	Pacific	Consolidation	Santa Fe	Atlantic	Atlantic	Atlantic	Atlantic	
K-2	K-29	W	900	De Glehn Compound	507	S8	I1	
P.R.R. Co.	P.R.R. Co.	M.C.R.R.	A.T. & S.F. R.R.	P.R.R. Co.	A. T. & S.F. R.R.	Royal Prussian R.R.	N.Y.C. & H. R.R.R.	
Altoona, Pa.	Altoona, Pa.	St. Louis, Mo.	St. Louis, Mo.	St. Louis, Mo.	St. Louis, Mo.	St. Louis, Mo.	St. Louis, Mo.	
3	3	4	5	2	2	2	2	1
80	80	63	56.5	80	79	78	79	2
4	4	2	2	4	4	4	4	14
36	36	33	28.5	37.824	34.25	39.48	36.48	15
56	54	....	39.9	60.780	50.2	39.48	50.0	16
13.84	13.85	16.99	19.768	7.058	6.834	6.890	7.00	17
35.21	36.50	25.79	35.885	28.569	30.288	29.540	27.75	18
47,334	50,500	24,500	25,860	41,250	51,880	39,200	50,000	20
55,467	66,000	44,200	53,110	44,550	52,000	33,625	55,100	21
62,000	65,800	44,800	58,100	43,300	47,200	31,725	54,900	22
61,167	66,000	39,800	45,760	....	....	....	....	23
....	....	35,700	36,110	....	....	....	....	24
....	....	....	40,680	....	....	....	....	25
46,133	68,700	....	26,120	34,900	50,420	28,800	40,000	26
272,101	317,000	189,000	285,740	164,000	201,500	133,350	200,000	27
178,634	197,800	164,500	233,760	82,850	99,200	65,350	110,000	28
2	2	1	2	2	2	2	2	29
....	....	1	2	2	2	2	2	30
Outside	Outside	Outside Cross Compound	Outside Tandem Compound	L. P. Inside H. P. Outside De Glehn Compound	L. P. Outside H.P. Inside Vau Clain Compound	L. P. Outside H. P. Inside Hanover Compound	L. P. Outside H.P. Inside Cole Compound	31
23.995	27.037	....	19.129	14.1847	15.034	14.166	15.510	32
23.994	27	23.096	19.165	14.1834	15.037	14.164	15.512	33
....	....	35.106	32.000	23.6550	25.023	22.048	26.006	34
....	....	....	32.000	23.6536	25.020	22.078	26.013	35
2.170	2.332	....	2.671	2.0975	2.166	1.968	2.163	36
2.163	2.338	2.667	2.668	2.0975	2.167	1.966	2.163	37
....	....	2.671	2.671	2.1025	2.167	1.969	2.166	38
....	....	....	2.668	2.1050	2.169	1.969	2.166	39
13.2	15.1	....	17.217	13.59	17.80	12.8	17.1	40
13.5	15.3	....	17.111	13.02	19.10	11.5	16.9	41
13.3	13.4	17.09	17.172	13.83	18.20	11.9	16.7	42
13.6	13.9	16.28	17.064	12.65	19.20	10.7	16.8	43
....	....	5.76	8.275	9.92	6.40	10.5	6.7	44
....	....	5.66	8.458	9.12	6.58	10.2	6.5	45
....	....	....	8.284	11.27	6.58	10.8	6.4	46
....	....	....	8.467	8.68	6.77	10.3	6.5	47
....	....	19.0	....	14.52	3.07	4.13	6.11	48
....	....	19.0	....	14.52	3.05	4.13	6.10	49
4.497	4.502	....	3.250	2.6763	3.255	3.147	3.000	74
4.499	4.501	3.998	3.250	2.6769	3.245	3.152	3.000	75
....	....	4.022	4.461	2.6755	3.245	2.755	3.002	76
....	....	....	4.461	2.6759	3.235	2.753	3.002	77
....	3.0	....	....	....	....	....	....	78
....	3.0	....	....	....	....	....	....	79
....	....	....	3.25	2.3609	....	1.968	....	80
....	....	....	3.25	2.3610	....	1.992	....	81

TABLE 4—PRINCIPAL DIMENSIONS

No. of Items*	Locomotive Number	Purdue No. 2	Purdue No. 3	1499	734	5266
	Valves					
82	Type	"D" Slide	"D" Slide	"D" Slide	"D" Slide	Wilson Balanced Double Ported Slide
83	Design	Richardson Balanced	Richardson Balanced	Richardson Balanced	Allen Richardson	American Balance Valve Co.
84	Per cent of balanced to total area	....	....	Left 58.97 Right 58.99	Left 53.13 Right 52.99	75.70
85	Type of Link motion	Stephenson	Stephenson	Stephenson	Stephenson	Stephenson
	Miscellaneous					
106	Cylinder lagging material	....	....	Magnesia	Magnesia	Magnesia
107	Cylinder jacket material	....	....	Sheet steel	Sheet iron	Sheet iron
	Boiler					
113	Type	Extended Wagon Type	Extended Wagon Type	Belpaire Wide Firebox	Extended Wagon Top Radial Stays	Belpaire Wide Firebox
114	Outside diameter, 1st ring, inches	52	52	71	68.375	67.0
	Tubes					
115	Number of Tubes	200	111	373	338	315
115	Number of Flues	....	16	....	....	....
116	Outside diameter of tubes, inches	2	2	2	2	2
116	Outside diameter of flues, inches	....	5	....	....	....
117	Thickness, inches	No. 12 Gage	No. 12 Gage	0.135	0.120	0.125
118	Length between tube sheets, inches	138	138	164.50	178.937	179.78
119	Total fire area, square	....	....	6.089	5.71	5.26
124	Boiler Pressure	250	250	205	200	205
	Superheater					
125	Number of Tubes	....	32	....	....	....
126	Outside diameter, inches	....	1.25	....	....	....
127	Thickness, inches	....	....	....	....	....
128	Length of tubes, inches	....	207.24	....	....	....
129	Type of Superheater	....	Cole	....	....	....
	Grates					
144	Style	....	....	Rocking Finger	Rocking	Rocking Finger
145	Total area, square feet	17	17	49.21	33.76	55.5
146	Total area, dead grates, square feet	....	....	0.0	0.0	6.0
147	Width of air spaces, inches	1.25	1.25	0.69	0.69	0.75
	Heating Surface, Square feet					
154	Of the tubes, water side	1196.00	897	2677.27	2638.97	2471.04
155	Of the tubes, fire side	1086.00	817	2315.86	2322.30	2162.40
156	Of the fire-box, fire side	126	126	166.40	218.92	156.86
157	Of the Superheater, fire side	....	193	....	....	....
158	Total, based on inside of fire-box and inside of tubes	1212.00	1136	2482.26	2541.22	2319.26
159	Total, based on inside of fire-box and outside of tubes	1322.00	1216	2843.67	2857.89	2627.90
	Constants for Piston Displacement, Cubic feet					
188	High Pressure Cylinder, right, head end	2.802	2.802	6.155	6.013	4.97
189	High Pressure Cylinder, right, crank end	2.720	2.720	5.952	5.823	4.83
190	High Pressure Cylinder, left, head end	2.849	2.849	6.153	6.025	5.11
191	High Pressure Cylinder, left, crank end	2.766	2.766	5.950	5.834	4.97
192	Low Pressure Cylinder, right, head end	....	....	....	....	....
193	Low Pressure Cylinder right, crank end	....	....	....	-..	....
194	Low Pressure Cylinder, left, head end	....	....	....	....	....
195	Low Pressure Cylinder, left, crank end	....	....	....	....	....

*Item numbers are the same as those given in the Reports of Tests at St. Louis Exposition.

OF ALL LOCOMOTIVES TESTED.—(*Continued.*)

7510	3395	585	929	2512	535	628	3000	No. of Items*
Piston	Piston	H.P.Piston L.P. "D" Slide	Piston	"D" Slide	Piston	H. P. Piston L.P. Allen Balanced	Piston	82
....	American Locomotive Company	H. P. Outside Admission; L.P. Allen Richardson	Baldwin Locomotive Works	L. P. Not Balanced; H.P. Balanced Ring	Baldwin Locomotive Works	Hanover	American Locomotive Company.	83
....	10.0	H. P. 90.63 L. P. 55.88	H. P. 72.5 L. P. 85.1	H. P. 40.92	H. P. 70.59 L. P. 75.31	H. P. 75.6 L. P. 44.7	H. P. 91.22 L. P. 90.79	84
Walscheart	Walscheart	Stephenson	Stephenson	Walscheart	Stephenson	Heusinger	Stephenson	85
Magnesia	Magnesia	Magnesia	Magnesia	Magnesia	Magnesia	Hair	Magnesia	106
Sheet iron	Sheet iron	Sheet steel	Sheet iron	Sheet iron	Sheet iron	Sheet iron	Sheet iron	107
Belpaire Wide Fire-box	Radial Stay Wide Fire-box	Straight Top Wide Fire-box	Wagon Top Radial Stay Wide Fire-box	Belpaire Straight Top	Wagon Top Radial Stay Wide Fire-box	Straight Top Wide Fire-box	Straight Top Wide Fire-box	113
80.0	....	70.125	81.05	59.664	69	62.24	72.25	114
359	241	363	393	139 Serve Tubes 8 Ribs No Flues	273	241	390	115
....	40	....	....		....	....	....	115
2.25	2.25	2	2.25	2.75	2.25	2	2	116
....	5.50	....	....	....	....	....	....	116
0.125	0.125	0.12	0.125	0.075	0.125	0.098	0.125	117
251.40	262.88	190.375	238.500	176.136	225.137	143.78	191.295	118
7.83	9.19	6.13	8.570	4.691	5.955	2.50	6.514	119
205	200	210	225	225	220	200	220	124
....	160	....	....	....	....	241	....	125
....	1.438	....	....	....	....	2	....	126
....	0.148	....	....	....	....	0.098	....	127
....	251.75	....	....	....	....	29.92	....	128
....	Schmidt	....	....	....	....	Pielock	....	129
Rocking Finger	Rocking Finger	Rocking	Rocking Finger	Stationary Wrought Iron Bars	Rocking Finger	Stationary	Rocking Finger	144
54.41	50.08 Incl. Retorts 70.73	49.43	58.41	33.39	48.36	29.06	49.90	145
0.0	1.82	0.0	0.0	0.0	0.0	0.0	0.0	146
0.78	0.375	0.75	0.94	0.50	1.06	0.5	0.75	147
4430.06	4373.31	3015.34	4601.00	1468.87	3016.71	1511.94	3255.27	154
3938.23	3968.27	2653.51	4089.77	2479.20	2681.75	1363.77	2848.36	155
192.47	232.84	165.69	216.36	177.28	220.30	105.59	151.69	156
....	1301.87	....	....	....	....	283.79	....	157
4130.70	4201.11	2819.20	4306.13	2656.48	2902.05	1753.15	3000.05	158
4622.53	4606.15	3181.03	4817.36	1646.15	3237.01	1932 16	3406.96	159
6.86	9.19	....	5.330	2.3020	2.6702	2.1539	2.8880	188
6.57	9.05	....	5.177	2.2199	2.5450	2.0475	2.7318	189
6.79	9.18	7.761	5.344	2.3014	2.6724	2.1511	2.8387	190
6.55	9.04	7.528	5.191	2.2190	2.5480	2.0446	2.7325	191
....	....	17.954	14.762	6.3520	7.4006	5.1786	7.9898	192
....	....	17.718	14.627	6.3340	7.2761	5.1389	7.8833	193
....	....	....	14.746	6.3595	7.4056	5.1918	7.9941	194
....	....	....	14.611	6.3413	7.2818	5.1534	7.8876	195

TABLE 5—Tests of Purdue Locomotive,

Number of Test	Laboratory Designation	Total Moist or Superheated Steam Passing thru Cylinders per hour	Total I. H. P.	Moist or Superheated Steam per I. H. P. hr., pounds	Pressure-lb. per sq. in.			Degrees of Superheat in Branch pipe Degrees F.
					In Boiler by Gage	In Branch-pipe by Gage	Barometer	
1	2	3	4	5	6	7	8	9
				TESTS AT 200 LB. GAGE PRESSURE				
29	20–2–200	6329	223.47	28.32	200.2	196.9	14.4	.....
30	20–4–200	7549	287.62	26.24	199.6	196.9	14.4	.....
31	20–6–200	9778	375.82	26.01	199.7	.....	14.5	.....
32	20–8–200	12443	472.90	26.31	200.3	195.6	14.4	.....
107	30–2–200	6431	280.44	22.93	200.1	196.8	14.6	131.6
108	30–4–200	8278	383.44	21.59	200.5	198.3	14.4	152.1
109	30–6–200	10306	516.97	19.93	200.2	199.1	14.5	169.1
33	30–2–200	7266	268.95	27.01	199.4	200.2	14.2	.....
34	30–4–200	9434	367.09	25.70	200.0	199.3	14.4	.....
35	30–6–200	12186	489.21	24.91	199.4	196.7	14.4	.....
110	40–2–200	6938	309.58	22.41	200.4	198.6	14.7	138.4
111	40–4–200	9844	466.51	21.09	200.1	193.7	14.3	152.9
112	40–6–200	11817	588.63	20.07	200.0	198.4	14.4	177.5
37	40–2–200	8243	306.58	26.88	200.4	195.9	14.5	.....
38	40–4–200	11073	448.88	24.66	201.6	.....	14.5	.....
39	40–6–200	14786	605.25	24.43	199.4	194.4	14.2	.....
113	50–4–200	9766	487.46	20.03	201.1	198.0	14.3	159.4
41	50–2–200	8471	329.05	25.74	200.5	197.8	14.4	.....
42	50–4–200	11972	464.20	25.78	200.6	196.2	14.3	.....
				TESTS AT 220 LB. GAGE PRESSURE				
13	20–2–220	7066	255.33	27.65	221.6	218.4	14.4	.....
14	20–4–220	8846	342.85	25.80	219.8	216.6	14.5	.....
15	20–6–220	11008	431.44	25.51	220.1	215.2	14.2	.....
16	20–8–220	13788	533.02	25.86	220.6	218.4	14.4	.....
17	30–2–220	8522	320.32	26.60	220.5	219.7	14.5	.....
18	30–4–220	10720	446.49	24.23	220.0	219.1	14.4	.....
19	30–6–220	13192	559.49	23.59	218.8	215.1	14.4	.....
21	40–2–220	9505	371.46	25.58	220.7	217.7	14.3	.....
22	40–4–220	12058	509.07	23.68	218.6	212.8	14.4	.....
24	50–2–220	9960	378.79	26.29	220.8	218.0	14.5	.....
25	50–4–220	13540	562.30	24.08	220.0	.....	14.4	.....
				TESTS AT 240 LB. GAGE PRESSURE				
1	20–2–240	7268	276.45	26.29	241.5	240.9	14.5	.....
2	20–4–240	9932	392.52	25.33	242.2	.....	14.4	.....
3	20–6–240	11247	466.82	24.09	238.3	237.2	14.4	.....
101	30–2–240	8662	369.76	23.43	241.0	237.3	14.5	137.8
102	30–4–240	10539	476.69	22.11	238.9	236.1	14.3	152.5
103	30–5–240	11580	534.07	21.68	234.3	225.4	14.4	149.1
5	30–2–240	9462	371.29	25.48	240.0	.....	14.6	.....
6	30–4–240	11500	470.64	24.43	240.2	235.1	14.5	.....
104	40–2–240	9078	415.09	21.89	236.4	231.4	14.5	127.3
105	40–4–240	11758	551.36	21.32	239.7	235.7	14.6	153.9
8	40–2–240	10192	421.78	24.16	242.0	240.5	14.3	.....
9	40–4–240	13511	566.30	23.86	241.0	239.2	14.4	.....
106	50–2–240	10038	463.87	21.64	235.8	231.4	14.4	142.7
11	50–2–240	11627	465.50	24.97	242.0	.....	14.5	.....

Schenectady Nos. 2 and 3.

Speed		Weight of Steam per Revolution, lb.				Quality of Steam Mixture at Cut-off, x_c, parts of unity	Average Value of n, From Expansion Curves	Av. Absolute Pressure, lb.-sq. in.	
Revolutions per min.	Revolutions per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present			At Cut-off	Back Pressure of Exhaust
10	11	14	15	16	17	18	19	20	21
TESTS AT 200 LB. GAGE PRESSURE									
97.09	5825	1.0865	0.829	0.2780	1.3645	0.608	0.955	159	16
96.97	5815	1.2979	1.017	0.2520	1.5499	0.656	0.978	153	16
97.52	5880	1.6730	1.305	0.2105	1.8835	0.693	0.962	154	17
97.25	5835	2.1325	1.702	0.1915	2.3240	0.732	1.014	161	17
146.90	8814	0.7296	0.757	0.2650	0.9946	0.761	0.985	143	16
146.20	8775	0.9439	0.973	0.2520	1.1959	0.813	1.057	144	16
148.00	8880	1.1605	1.254	0.2475	1.4080	0.891	1.071	150	17
146.11	8766	0.8288	0.753	0.3025	1.1313	0.665	0.971	150	16
146.19	8772	1.0756	0.969	0.2815	1.3571	0.714	0.973	146	16
146.14	8768	1.3896	1.201	0.2620	1.6516	0.727	1.039	144	17
194.50	11670	0.5945	0.769	0.3310	0.9255	0.831	1.022	138	16
196.88	11810	0.8333	0.935	0.2670	1.1003	0.850	1.071	131	16
198.80	11925	0.9906	1.188	0.2760	1.2666	0.937	1.123	131	17
194.78	11680	0.7053	0.711	0.3170	1.0223	0.695	0.972	136	16
194.85	11690	0.9471	0.894	0.3220	1.2691	0.704	0.980	138	16
194.67	11670	1.2658	1.159	0.3105	1.5763	0.735	1.036	133	17
234.90	14090	0.6929	0.934	0.3250	1.0179	0.917	1.084	124	16
243.38	14610	0.5800	0.684	0.3270	0.9070	0.754	1.003	128	16
243.85	14625	0.8183	0.831	0.3320	1.1503	0.722	1.004	123	16
TESTS AT 220 LB. GAGE PRESSURE									
96.83	5810	1.3028	0.910	0.2700	1.5728	0.579	0.924	169	16
97.57	5852	1.5110	1.156	0.2500	1.7610	0.656	0.972	173	16
97.39	5840	1.8839	1.472	0.2180	2.1019	0.700	1.002	178	17
97.80	5878	2.3496	1.890	0.2205	2.5701	0.735	1.005	185	17
146.05	8760	0.9726	0.834	0.3070	1.2796	0.652	0.972	170	16
146.15	8761	1.2225	1.074	0.2910	1.5135	0.710	1.000	155	16
146.26	8775	1.5033	1.360	0.2900	1.7933	0.758	1.019	158	17
195.29	11710	0.8110	0.795	0.3200	1.1310	0.703	0.988	148	16
194.71	11680	1.0320	0.981	0.3190	1.3510	0.726	1.000	146	16
243.41	14604	0.6819	0.737	0.3280	1.0099	0.736	1.010	138	16
243.43	14606	0.9270	0.944	0.3326	1.2590	0.750	1.014	135	16
TESTS AT 240 LB. GAGE PRESSURE									
94.49	5670	1.2819	0.968	0.2980	1.5799	0.612	0.926	189	16
97.72	5861	1.6940	1.292	0.2610	1.9550	0.661	0.987	194	16
97.09	5825	1.9300	1.540	0.2525	2.1825	0.705	0.935	190	17
147.10	8825	0.9814	0.960	0.3215	1.3029	0.736	0.963	180	16
141.65	8500	1.2400	1.165	0.2740	1.5140	0.770	1.015	170	16
143.29	8595	1.3468	1.283	0.2675	1.6143	0.795	1.031	168	17
146.15	8765	1.0790	0.957	0.3240	1.4030	0.682	0.964	176	16
146.00	8760	1.3120	1.131	0.3025	1.6145	0.701	0.966	171	16
193.55	11620	0.7817	0.873	0.3070	1.0887	0.802	1.002	160	16
193.00	11580	1.0150	1.125	0.3150	1.3300	0.846	1.024	155	16
194.46	11660	0.8735	0.850	0.3260	1.1995	0.709	0.968	166	16
194.63	11680	1.1565	1.076	0.3315	1.4880	0.723	0.987	155	16
246.41	14790	0.6789	0.826	0.3045	0.9834	0.840	1.041	146	16
248.38	14910	0.7801	0.827	0.3515	1.1316	0.730	1.004	148	16

TABLE 5—Tests of Purdue Locomotive,

Number of Test	Laboratory Designation	Total Moist or Superheated Steam Passing thru Cylinders per hour	Total I. H. P.	Moist or Superheated Steam per I. H. P. hr., pounds	Pressure, lb. per sq. in.			Degrees of Superheat in Branch pipe Degrees F.
					In Boiler by Gage	In Branch-pipe by Gage	Barometer	
1	2	3	4	5	6	7	8	9
TESTS AT 120 LB. GAGE PRESSURE								
* 85	20- 4-120†	4351	134.00	32.47	120.4	117.9	14.3	.....
86	20- 8-120	7180	252.79	28.40	121.3	118.0	14.2	.....
87	20-12-120	10312	356.91	28.88	120.0	115.6	14.3	.....
129	30- 4-120	4454	163.30	27.27	120.2	118.7	14.5	117.1
130	30- 8-120	7726	335.27	23.05	120.2	.....	....	156.2
131	30-10-120	9043	409.72	22.07	119.9	120.9	14.4	174.9
132	30-14-120	11672	517.49	22.56	120.2	119.5	14.2	191.4
88	30- 4-120	5238	171.02	30.63	120.5	119.1	14.4	.....
89	30- 8-120	8939	325.49	27.46	120.4	117.4	14.3	.....
90	30-14-120	15584	514.01	30.31	120.1	114.3	14.4	.....
133	40- 4-120	4714	178.58	26.39	120.1	119.0	14.6	120.8
134	40- 8-120	8530	382.89	22.27	120.3	120.0	14.4	170.6
135	40-12-120	12156	547.57	22.20	120.6	118.3	14.7	190.3
91	40- 4-120	5556	184.04	30.18	120.3	117.4	14.4	.....
92	40- 8-120	10702	389.05	27.51	120.5	117.1	14.5	.....
93	40-12-120	15830	554.77	28.52	119.9	119.1	14.4	.....
136	50- 8-120	9368	411.80	22.74	120.6	117.5	14.7	169.1
94	50- 4-120	5957	176.03	33.84	119.9	118.6	14.4	.....
95	50- 8-120	12024	427.59	28.12	120.3	117.8	14.5	.....
96	50-11-120	16149	553.53	29.17	120.1	110.0	14.4	.....
TESTS AT 160 LB. GAGE PRESSURE								
114	20- 2-160	4521	166.77	27.11	160.2	.....	14.7	125.0
115	20- 4-160	5504	232.15	23.71	160.5	.....	14.5	133.4
116	20- 6-160	6913	300.16	23.03	159.9	.....	14.4	153.8
117	20- 8-160	8367	366.71	22.82	159.5	.....	14.3	145.1
67	20- 4-160	6153	219.52	28.03	160.2	159.1	14.4	.....
68	20- 6-160	7802	298.41	26.14	160.2	158.5	14.4	.....
69	20- 8-160	9494	345.05	27.52	159.3	157.3	14.3	.....
118	30- 2-160	5014	191.53	26.18	160.8	160.6	14.4	125.0
119	30- 4-160	6543	285.39	22.93	160.2	159.7	14.4	141.9
120	30- 6-160	8565	387.36	22.11	160.4	.....	14.5	162.9
121	30- 8-160	10214	481.82	21.20	160.1	158.6	14.3	172.9
71	30- 4-160	7311	272.11	26.86	160.7	160.3	14.4	.....
72	30- 6-160	9705	383.86	25.28	159.7	158.6	14.5	.....
73	30- 8-160	11947	465.05	25.69	162.2	159.9	14.4	.....
122	40- 2-160	5378	211.46	25.46	161.1	160.0	14.5	123.4
123	40- 4-160	7389	343.28	21.52	159.9	.....	14.7	154.0
124	40- 6-160	9213	429.80	21.44	160.0	.....	14.4	164.9
125	40- 8-160	12145	598.70	20.29	160.4	.....	14.4	180.1
76	40- 4-160	8408	317.72	26.48	161.0	156.9	14.3	.....
77	40- 6-160	11145	431.66	25.82	160.6	154.7	14.4	.....
78	40- 8-160	14380	543.87	26.44	161.1	158.0	14.5	.....
126	50- 2-160	5238	180.24	29.06	161.2	159.6	14.5	118.1
127	50- 4-160	7621	343.05	22.21	160.4	159.4	14.8	152.5
80	50- 4-160	9137	338.27	27.01	159.8	158.4	14.4	.....
81	50- 6-160	12432	475.87	26.12	160.0	155.6	14.4	.....
TESTS AT 180 LB. GAGE PRESSURE								
46	20- 2-180	5525	191.97	28.78	183.0	181.2	14.6	.....
47	20- 4-180	7054	263.59	26.76	181.6	179.0	14.5	.....
48	20- 6-180	8499	334.07	25.44	180.0	176.5	14.5	.....
49	20- 8-180	10668	411.70	25.91	180.3	177.7	14.5	.....
51	30- 2-180	6257	235.15	26.54	181.6	178.6	14.2	.....
52	30- 4-180	8090	317.15	25.36	178.6	178.9	14.5	.....
53	30- 6-180	9685	393.27	24.62	170.0	170.0	14.6	.....
54	30- 8-180	13447	546.26	24.61	179.4	175.5	14.4	.....
56	40- 2-180	6711	259.13	25.89	182.3	178.9	14.5	.....
57	40- 4-180	9301	386.18	24.08	181.1	178.8	14.5	.....
58	40- 6-180	12401	524.08	23.68	179.8	176.2	14.5	.....
59	40- 8-180	15771	609.91	25.85	177.7	177.4	14.2	.....
61	50- 2-180	7133	268.02	26.61	182.3	181.6	14.3	.....
62	50- 4-180	10032	410.62	24.43	181.3	176.7	14.5	.....
63	50- 6-180	13766	553.30	24.87	180.7	175.5	14.3	.....

* Tests 1–97 run with saturated steam. 101–136 with superheated steam. † Laboratory Designatio
gauge pressure.

SCHENECTADY NOS. 2 AND 3.—(*Continued.*)

Speed		Weight of Steam per Revolution, lb.				Quality of Steam Mixture at Cut-off, x_c, parts of unity	Average Value of n, From Expansion Curves	Av. Absolute Pressure, lb.-sq. in.	
Revolutions per min.	Revolutions per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present			At Cut-off	Back Pressure of Exhaust
10	11	14	15	16	17	18	19	20	21
TESTS AT 120 LB. GAGE PRESSURE									
97.33	5840	0.7450	0.622	0.2420	0.9870	0.630	0.944	98	16
97.08	5825	1.2320	1.005	0.1835	1.4155	0.710	0.999	98	17
97.04	5822	1.7710	1.502	0.1645	1.9356	0.776	1.027	104	19
146.20	8772	0.5075	0.567	0.2550	0.7625	0.744	0.957	89	16
147.37	8842	0.8737	0.951	0.1990	1.0727	0.886	1.076	90	17
145.13	8708	1.0384	1.167	0.1665	1.2049	0.969	1.134	90	18
146.03	8762	1.3322	1.600	0.1560	1.4882	1.075	1.158	99	20
146.15	8769	0.5973	0.568	0.2510	0.8483	0.669	0.972	90	16
146.45	8787	1.0720	0.910	0.2145	1.2865	0.707	1.021	88	17
145.81	8749	1.7813	1.611	0.1820	1.9633	0.821	1.024	100	20
194.52	11671	0.4039	0.562	0.2570	0.6609	0.851	1.031	85	16
194.55	11673	0.7305	0.904	0.2075	0.9380	0.964	1.120	85	17
194.61	11677	1.0219	1.315	0.2080	1.2299	1.069	1.192	91	19
195.03	11702	0.4747	0.531	0.2695	0.7442	0.713	0.984	85	16
195.01	11701	0.9145	0.875	0.2450	1.1595	0.754	1.026	83	17
195.38	11723	1.3503	1.296	0.2320	1.5823	0.819	0.997	91	19
243.87	14632	0.6406	0.852	0.2380	0.8786	0.970	1.150	76	17
243.71	14623	0.4074	0.525	0.2755	0.6829	0.769	0.979	76	16
243.45	14607	0.8232	0.852	0.2750	1.0982	0.776	0.977	79	17
246.10	14766	1.0936	1.110	0.2365	1.3301	0.835	1.000	80	19
TESTS AT 160 LB. GAGE PRESSURE									
97.15	5829	0.7755	0.683	0.2480	1.0235	0.667	0.923	128	16
97.06	5824	0.9451	0.851	0.2110	1.1561	0.736	0.985	127	16
97.44	5846	1.1823	1.075	0.1805	1.3628	0.789	1.027	126	17
97.61	5860	1.4285	1.348	0.1660	1.5945	0.845	1.091	127	17
97.34	5840	1.0536	0.824	0.2120	1.2656	0.651	0.966	123	16
97.49	5849	1.3245	1.084	0.2100	1.5345	0.706	0.983	129	17
97.39	5843	1.6229	1.295	0.1925	1.8154	0.713	0.991	125	17
146.44	8786	0.5707	0.625	0.2650	0.8357	0.748	0.950	124	16
145.45	8727	0.7497	0.800	0.2220	0.9717	0.823	0.997	115	16
146.11	8767	0.9769	0.993	0.2240	1.2009	0.827	1.074	115	17
146.27	8776	1.1635	1.250	0.2150	1.3785	0.907	1.113	119	17
145.96	8758	0.8323	0.763	0.2520	1.0843	0.704	0.992	119	16
146.11	8767	1.0071	0.985	0.2480	1.2551	0.784	1.030	119	17
146.42	8785	1.3594	1.218	0.2475	1.6069	0.757	0.985	119	17
199.26	11956	0.4498	0.615	0.2955	0.7453	0.825	1.020	113	16
196.02	11761	0.6282	0.783	0.3055	0.9337	0.839	1.047	106	16
195.25	11715	0.7864	0.936	0.2485	1.0349	0.905	1.095	109	17
195.27	11716	1.0364	1.207	0.2130	1.2494	0.966	1.153	111	17
195.27	11716	0.7176	0.740	0.2940	1.0116	0.731	1.019	107	16
194.68	11681	0.9541	0.919	0.2960	1.2501	0.735	1.017	110	17
195.85	11751	1.2237	1.122	0.2745	1.4982	0.749	1.006	107	17
243.17	14590	0.3589	0.547	0.3070	0.6659	0.822	1.010	105	16
242.91	14575	0.5228	0.703	0.2860	0.8088	0.869	1.054	100	16
243.61	14617	0.6251	0.671	0.2840	0.9091	0.738	0.997	96	16
243.86	14632	0.8497	0.874	0.2920	1.1417	0.765	1.023	96	17
TESTS AT 180 LB. GAGE PRESSURE									
97.74	5862	0.9472	0.739	0.2870	1.2342	0.599	0.878	146	16
97.74	5870	1.2016	0.943	0.2705	1.4721	0.640	0.905	139	16
97.69	5860	1.4510	1.193	0.2265	1.6775	0.711	0.976	145	17
97.66	5859	1.8234	1.475	0.2085	2.0319	0.725	0.980	146	17
146.76	8805	0.7105	0.700	0.2940	1.0045	0.697	0.954	144	16
145.37	8720	0.9275	0.847	0.2910	1.2185	0.695	0.960	134	16
146.00	8760	1.1050	1.015	0.2640	1.3690	0.741	0.988	125	17
146.76	8805	1.5480	1.360	0.2475	1.7955	0.757	0.992	126	17
194.92	11690	0.5737	0.660	0.3095	0.8832	0.747	0.967	129	16
195.12	11710	0.7940	0.833	0.3165	1.1105	0.750	1.015	128	16
193.64	11618	1.0673	1.026	0.3560	1.4233	0.721	0.956	125	17
196.72	11615	1.3354	1.251	0.2910	1.6264	0.769	1.032	125	17
243.55	14610	0.4880	0.635	0.3100	0.7980	0.796	0.997	125	16
242.77	14560	0.6885	0.771	0.3245	1.0130	0.761	1.006	116	16
247.06	14825	0.9280	0.958	0.3205	1.2485	0.767	0.997	109	17

denotes in order, miles per hour, number of notches reverse lever is forward of dead-center position, and boiler

TABLE 6—Tests of Penn. R. R. Class H6a

Number of Test	Laboratory Designation	Total Moist Steam passing thru Cylinders per hr.	Total I. H. P.	Moist Steam in lb. per I. H. P. hr.	Pressure, lb. per sq. in. In Boiler by Gage	Pressure, lb. per sq. in. Barometer	Speed Revolutions per min.	Speed Revolutions per hr.
1	2	3	4	5	6	8	10	11
110	40–20–F†	10445	365.7	28.57	200.4	14.5	40.33	2420
111	40–30–F	12493	454.5	27.49	203.4	14.5	40.42	2425
103	80–20–F	16748	650.0	25.77	197.6	14.4	92.74	5564
109	80–20–F	14995	587.6	25.52	191.6	14.4	81.59	4895
112	80–30–F	18796	779.3	24.11	200.7	14.5	79.73	4784
118	80–37–F	23176	930.5	24.90	201.4	14.5	80.69	4841
116	120–30–F	23046	975.1	23.63	198.7	14.5	120.12	7207
115	120–35–F	24799	1036.1	23.92	193.1	14.4	120.63	7238
102	160–20–F	20068	803.3	24.99	189.3	14.5	160.33	9620
105	160–27–F	22750	951.4	23.91	181.6	14.6	157.64	9458
117	160–35–P	25496	1023.7	24.90	201.8	14.5	160.63	9638

TABLE 7—Tests of L. S. & M. S. Class B1

201	40–20–F	8942	299.4	29.88	192.8	14.6	40.34	2420
203	40–40–F	15174	550.4	27.58	199.6	14.5	40.11	2407
204	80–45–F	23732	901.1	26.33	178.0	14.5	79.99	4799
205	80–20–F	13810	527.0	26.20	200.3	14.6	80.46	4828
206	80–30–F	19412	782.6	24.81	201.8	14.5	80.07	4804
208	80–40–F	24283	962.5	25.22	204.0	14.5	80.00	4800
209	160–20–F	21948	865.6	25.36	201.5	14.4	159.31	9559
210	160–23–F	23763	953.7	24.92	198.5	14.4	159.94	9596
211	160–27–F	26149	994.8	26.28	178.4	14.4	160.01	9601
212	160–26–F	25481	1053.9	24.18	199.4	14.5	160.32	9619
213	160–40–P	24770	886.8	27.92	202.6	14.5	160.39	9623
217	160–40–P	24300	799.5	30.40	199.3	14.5	159.23	9554
218	160–40–P	24495	865.2	28.31	200.8	14.5	160.10	9606
219	160–30–P	23822	923.4	25.81	200.7	14.6	158.82	9529
220	160–26–P	23287	942.4	24.90	201.6	14.5	160.05	9603

TABLE 8—Tests of Penn R. R. Class E2a

901	80–15–F	14227	419.8	33.89	201.3	14.1	80.00	4800
902	80–20–F	15545	477.2	32.56	200.1	14.2	80.00	4800
904	80–25–F	18124	585.6	30.98	198.5	14.2	80.00	4800
906	80–30–F	22030	727.9	30.30	202.6	14.2	80.00	4800
908	120–20–F	19747	687.6	28.72	201.0	14.1	120.00	7200
910	120–25–F	22946	851.1	26.98	200.5	14.1	120.00	7200
912	120–30–F	26941	1015.4	26.52	202.7	14.1	120.00	7200
913	160–15–F	20222	748.8	27.01	198.0	14.2	160.00	9600
914	160–20–F	21166	826.8	25.60	202.9	14.3	160.00	9600
916	160–25–F	25791	1011.6	25.49	200.0	14.4	160.00	9600
917	160–27–F	28242	1055.0	26.78	188.4	14.2	160.00	9600
920	200–20–F	25557	1018.6	25.09	202.0	14.1	200.00	12000
922	200–25–F	29468	1223.7	24.08	202.1	14.3	200.00	12000

†Laboratory Designation denotes in order, revolutions per minute, cut-off in per-cent of stroke, and full or

Locomotive No. 1499, Consolidation Type.

Speed		Weight of Steam per Revolution, lb.				Quality of Steam Mixture at Cut-off, x_c, parts of unity	Average Value of n, From Expansion Curves	Av. Absolute Pressure, lb.-sq. in.	
Piston Speed, ft. per min.	Miles per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present			At Cut-off	Back Pressure of Exhaust
12	13	14	15	16	17	18	19	20	21
188.1	6.70	4.315	3.251	0.548	4.863	0.669	1.136	175	15
188.5	6.72	5.150	3.967	0.486	5.637	0.704	1.111	180	15
432.6	15.40	3.007	2.770	0.631	3.638	0.762	1.065	158	16
380.5	13.55	3.062	2.780	0.649	3.711	0.749	1.068	155	15
371.8	13.24	3.928	3.520	0.540	4.468	0.788	1.097	160	16
376.3	13.40	4.784	4.405	0.459	5.243	0.840	1.125	161	17
560.2	19.95	3.200	3.128	0.622	3.822	0.818	1.091	145	18
562.6	20.04	3.427	3.286	0.604	4.031	0.815	1.087	132	18
747.7	26.63	2.085	2.275	0.744	2.829	0.805	1.049	124	18
735.3	26.20	2.405	2.520	0.690	3.095	0.814	1.044	124	19
949.2	26.68	2.646	2.793	0.673	3.319	0.842	1.128	108	19

Locomotive No. 734, Consolidation Type.

201.7	7.56	3.698	2.842	0.616	4.314	0.659	1.012	195	17
200.5	7.52	6.303	5.695	0.452	6.755	0.844	1.065	200	17
399.9	14.99	4.949	4.676	0.574	5.523	0.847	1.066	169	22
402.2	15.09	2.863	2.721	0.754	3.617	0.753	1.025	191	19
400.3	15.01	4.043	3.698	0.679	4.722	0.783	1.038	186	20
399.9	14.99	5.058	4.780	0.686	5.744	0.832	1.052	185	23
796.4	29.87	2.298	2.588	1.063	3.361	0.769	1.043	170	23
799.6	29.98	2.476	2.670	0.892	3.368	0.792	1.063	157	22
799.9	30.00	2.723	2.837	0.882	3.605	0.787	1.037	149	24
801.0	30.04	2.648	2.910	0.872	3.520	0.827	1.045	156	24
801.8	30.07	2.572	2.774	0.722	3.294	0.842	1.061	106	23
796.0	29.85	2.543	2.560	0.744	3.287	0.780	1.018	100	22
800.4	30.01	2.549	2.599	0.645	3.194	0.813	1.047	105	22
793.9	29.77	2.501	2.792	0.839	3.340	0.836	1.103	134	23
800.1	30.00	2.444	2.701	0.912	3.356	0.805	1.055	165	21

Locomotive No. 5266, Atlantic Type.

346.2	19.10	2.964	2.131	0.492	3.456	0.617	0.941	180	16
346.2	19.10	3.238	2.359	0.473	3.711	0.635	0.949	175	16
346.2	19.10	3.776	2.838	0.450	4.226	0.671	1.042	180	16
346.2	19.10	4.592	3.461	0.395	4.987	0.694	0.946	190	17
519.2	28.65	2.741	2.310	0.495	3.236	0.714	1.042	173	18
519.2	28.65	3.188	2.780	0.490	3.678	0.756	1.053	176	18
519.2	28.65	3.742	3.285	0.429	4.171	0.788	1.025	171	17
692.4	38.20	2.108	1.911	0.517	2.625	0.728	0.993	150	18
692.4	38.20	2.203	2.082	0.532	2.735	0.762	1.004	149	17
692.4	38.20	2.686	2.508	0.466	3.152	0.796	1.059	161	17
692.4	38.20	2.942	2 589	0.488	3.430	0.755	1.043	150	19
865.6	47.75	2.130	2.047	0.540	2.670	0.766	0.998	147	19
865.6	47.75	2.453	2.421	0.532	2.985	0.811	1.018	146	21

partial throttle opening.

TABLE 9—Tests of Penn. R. R. Class K2

Number of Test	Laboratory Designation	Total Moist Steam passing thru Cylinders per hr.	Total I. H. P.	Moist Steam in lb. per I. H. P. hr.	Pressure, lb. per sq. in.		Speed	
					In Boiler by Gage	Barometer	Revolutions per min.	Revolutions per hr.
1	2	3	4	5	6	8	10	11
1609	80–20–F	18910	747.5	25.29	203.1	14.1	80	4800
1636	80–25–F	20008	793.3	25.23	204.8	14.1	80	4800
1638	80–15–F	16676	643.0	25.93	205.2	14.1	80	4800
1601	80–15–F	15745	605.0	26.02	196.8	14.2	80	4800
1602	80–25–F	21384	848.0	25.20	202.4	14.1	80	4800
1607	80–25–F	21413	852.6	25.13	202.8	14.2	80	4800
1637	80–15–F	16009	612.3	26.05	203.8	14.1	80	4800
1643	80–25–F	20049	833.9	24.02	203.3	14.1	80	4800
1646	80–15–F	14918	573.2	26.03	205.4	14.2	80	4800
1610	100–30–F	29201	1172.0	24.92	203.3	14.2	100	6000
1603	120–25–F	29057	1202.9	24.17	202.7	14.3	120	7200
1605	120–35–F	36363	1455.3	24.98	203.5	14.1	120	7200
1644	120–30–F	28840	1188.9	24.26	205.2	14.1	120	7200
1611	120–30–F	33951	1371.0	24.77	203.6	14.0	120	7200
1635	120–30–F	29023	1227.9	23.62	203.2	14.0	120	7200
1647	120–30–F	29660	1199.2	24.72	204.1	14.2	120	7200
1604	160–25–F	34569	1475.8	23.41	204.8	14.1	160	9600
1622	160–25–F	32491	1201.8	27.03	202.2	14.2	160	9600
1634	160–35–F	40745	1657.1	24.58	202.5	14.0	160	9600
1649	160–30–F	31858	1309.0	24.32	193.8	14.2	160	9600
1606	160–35–F	42240	1699.4	24.86	202.4	14.2	160	9600
1608	160–25–F	33072	1384.2	23.90	204.4	14.2	160	9600
1612	160–25–F	33133	1400.9	23.66	204.1	14.0	160	9600
1624	180–30–F	35903	1497.3	23.98	197.5	14.0	180	10800
1631	180–35–F	42896	1723.2	24.91	203.1	14.0	180	10800
1613	180–35–F	44130	1773.8	24.89	201.2	14.2	180	10800
1633	180–35–F	43407	1773.5	24.51	203.0	14.0	180	10800
1645	180–35–F	44276	1754.5	25.24	202.6	14.2	180	10800

TABLE 10—Tests of Penn. R. R. Class K-29

Number of Test	Laboratory Designation	Total Superheated Steam passing thru Cylinders per hr.	Total I. H. P.	Superheated Steam in lb. per I. H. P. hr.	Pressure, lb. per sq. in.			Degrees of Superheat in Branch Pipe	Speed	
					In Boiler by Gage	In Branch Pipe by Gage	Barometer		Revolutions per min.	Revolutions per hr.
1	2	3	4	5	6	7	8	9	10	11
2434	100–20–F	19525	941.0	20.68	200.1	197.0	13.8	176.2	100	6000
2402	100–23–F	23756	1100.5	21.58	192.4	189.0	14.3	177.6	100	6000
2403	100–23–F	22257	1090.7	20.40	187.5	185.5	14.2	183.2	100	6000
2435	120–25–F	26740	1386.5	19.28	200.1	195.4	13.8	200.3	120	7200
2416	160–31–F	33747	1840.7	18.33	200.4	193.7	14.1	234.4	160	9600
2436	160–31–F	31866	1762.5	18.07	199.8	192.2	14.1	226.0	160	9600
2414	160–31–F	30941	1833.5	16.88	202.0	194.3	14.3	252.0	160	9600
2413	180–31–F	32449	1978.3	16.40	201.2	194.3	14.4	231.4	180	10800
2422	180–38–F	40405	2246.5	17.99	200.5	191.2	14.0	253.7	180	10800
2417	180–38–F	39317	2141.0	18.35	190.9	181.7	14.1	252.8	180	10800
2438	180–40–F	43387	2242.6	19.32	200.0	184.3	14.3	244.4	180	10800
2437	180–42–F	44540	2269.1	19.64	197.4	181.7	14.1	250.3	180	10800
2441	240–25–F	35142	1955.1	17.97	199.9	189.4	14.2	217.7	240	14400
2430	240–31–F	38564	2207.7	17.47	199.9	190.1	14.0	233.1	240	14400
2439	240–35–F	40382	2283.6	17.66	200.6	185.6	14.3	247.0	240	14400
2433	240–35–F	42610	2251.3	18.11	200.5	186.8	14.1	240.2	240	14400
2440	280–35–F	44338	2405.8	18.43	201.5	185.3	14.1	241.2	280	16800
2442	280–35–F	45333	2359.4	19.22	199.8	182.0	14.1	236.6	280	16800

LOCOMOTIVE NO. 7510, PACIFIC TYPE.

Speed		Weight of Steam per Revolution, lb.				Quality of Steam Mixture at Cut-off, x_c, parts of unity	Average Value of n, From Expansion Curves	Av. Absolute Pressure, lb.-sq. in.	
Piston Speed, ft. per min.	Miles per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present			At Cut-off	Back Pressure of Exhaust
12	13	14	15	16	17	18	19	20	21
346.6	19.03	3.940	3.688	0.555	4.495	0.820	1.114	169	17
346.6	19.03	4.168	3.920	0.562	4.730	0.829	1.069	180	18
346.6	19.03	3.474	3.218	0.622	4.096	0.785	1.067	171	19
346.6	19.03	3.280	3.030	0.566	3.846	0.788	1.061	168	18
346.6	19.03	4.456	4.169	0.505	4.961	0.840	1.099	169	17
346.6	19.03	4.462	4.130	0.543	5.005	0.825	1.078	168	18
346.6	19.03	3.336	3.132	0.637	3.973	0.788	1.094	170	17
346.6	19.03	4.178	3.900	0.560	4.738	0.823	1.057	166	18
346.6	18.95	3.108	2.865	0.568	3.676	0.780	1.066	148	19
433.3	23.78	4.867	4.710	0.522	5.389	0.874	1.100	172	20
520.0	28.54	4.037	3.978	0.560	4.597	0.865	1.074	160	20
520.0	28.54	5.050	4.990	0.564	5.614	0.889	1.118	170	22
520.0	28.43	4.006	3.990	0.533	4.539	0.880	1.107	155	22
520.0	28.54	4.718	4.691	0.523	5.241	0.895	1.104	165	22
520.0	28.54	4.032	4.020	0.539	4.571	0.879	1.124	156	20
520.0	28.43	4.119	3.995	0.533	4.652	0.859	1.082	148	21
693.3	38.05	3.601	3.667	0.568	4.169	0.879	1.100	144	22
693.3	38.05	3.384	3.204	0.696	4.080	0.786	1.092	139	23
693.3	38.05	4.245	4.240	0.592	4.837	0.877	1.146	150	26
693.3	37.91	3.318	3.437	0.599	3.917	0.877	1.080	139	23
693.3	38.05	4.402	4.486	0.642	5.044	0.889	1.118	149	26
693.3	38.05	3.447	3.579	0.654	4.101	0.872	1.124	148	23
693.3	38.05	3.452	3.520	0.644	4.096	0.860	1.134	152	21
779.9	42.81	3.325	3.412	0.692	4.017	0.850	1.127	136	24
779.9	42.81	3.971	3.993	0.687	4.658	0.858	1.114	147	28
779.9	42.81	4.087	4.243	0.707	4.794	0.885	1.087	143	28
779.9	42.81	4.020	4.074	0.622	4.642	0.878	1.119	140	26
779.9	42.65	4.099	4.080	0.643	4.742	0.860	1.074	140	28

LOCOMOTIVE NO. 3395, PACIFIC TYPE

Speed		Weight of Steam per Revolution, lb.				Quality of Steam Mixture at Cut-off, x_c, parts of unity	Average Value of n, From Expansion Curves	Av. Absolute Pressure, lb. sq. in.	
Piston Speed, ft. per min.	Miles per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present			At Cut-off	Back Pressure of Exhaust
12	13	14	15	16	17	18	19	20	21
467.0	23.66	3.254	4.055	0.742	3.996	1.015	1.225	150	16
467.0	23.76	3.959	4.442	0.691	4.650	0.956	1.233	149	16
467.0	23.76	3.710	4.378	0.668	4.378	1.000	1.232	141	15
560.4	28.39	3.715	4.908	0.805	4.520	1.086	1.270	146	22
747.2	38.02	3.515	5.020	0.869	4.384	1.145	1.279	140	22
747.2	37.86	3.319	5.260	0.892	4.211	1.249	1.305	136	25
747.2	38.02	3.224	5.120	0.922	4.146	1.235	1.347	134	23
840.6	42.77	3.003	4.890	0.979	3.982	1.228	1.265	140	22
840.6	42.77	3.741	5.770	1.002	4.734	1.215	1.309	136	28
840.6	42.77	3.641	5.500	0.959	4.600	1.195	1.286	128	27
840.6	42.59	4.016	6.100	1.078	5.094	1.197	1.293	142	31
840.6	42.59	4.124	6.180	1.023	5.147	1.200	1.341	134	32
1120.8	56.78	2.440	4.201	1.202	3.642	1.154	1.222	135	28
1120.8	57.03	2.678	4.518	1.150	3.828	1.180	1.320	125	28
1120.8	56.78	2.802	4.853	1.240	4.042	1.200	1.239	132	33
1120.8	57.03	2.960	4.910	1.196	4.156	1.182	1.271	123	33
1307.6	66.25	2.640	4.751	1.451	4.091	1.161	1.316	114	36
1307.6	66.25	2.699	4.730	1.364	4.063	1.164	1.254	120	36

TABLE 11—TESTS OF M. C. R. R.

					Pressure, lb. per sq. in.		Speed				High Pressure Cylinder Wt. of Steam per Revolution	
Number of Test	Laboratory Designation	Total Moist Steam passing thru Cylinders per hr.	Total I. H. P.	Moist Steam per I. H. P. hr., lb.	In Boiler by Gage	Barometer	Revolutions per min.	Revolutions per hr.	Piston Speed, ft. per min.	Miles per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off
1	2	3	4	5	6	8	10	11	12	13	14	15
301	40–43–F	9052	442.5	20.45	209.2	14.4	40.00	2400	213.5	7.49	3.771	3.833
302	40–45–F	9710	477.4	20.32	209.1	14.4	39.99	2399	213.5	7.49	4.048	4.060
303	40–48–F	10498	512.0	20.50	210.1	14.5	40.01	2401	213.6	7.49	4.371	4.324
305	80–45–F	16631	840.6	19.78	209.6	14.5	79.86	4792	426.3	14.96	3.471	3.882
306	80–42–F	14997	734.9	20.40	205.8	14.5	80.18	4811	428.0	15.01	3.118	3.550
308	80–53–F	18583	932.2	19.93	206.4	14.5	80.00	4800	427.1	14.98	3.872	4.251
309	80–57–F	21087	1040.7	20.25	210.9	14.5	79.98	4799	426.9	14.98	4.394	4.782
312	160–47–F	20883	890.1	23.45	209.0	14.6	160.02	9601	854.3	29.97	2.173	3.290
316	160–62–F	24673	1001.3	24.61	175.1	14.5	159.97	9598	854.1	29.96	2.572	3.580
317	160–50–P	19241	910.4	21.12	208.7	14.6	159.95	9597	853.9	29.96	2.006	3.159
318	160–61–P	22349	937.7	23.84	210.7	14.6	160.03	9602	854.3	29.97	2.327	3.165
319	160–65–P	22805	934.2	24.42	208.3	14.6	160.01	9601	854.3	29.97	2.377	3.059

TABLE 12—TESTS OF A. T. & S. F.

401	40–27–F	10485	391.6	26.80	215.4	14.5	40.01	2400.6	213.58	6.719	4.368	4.060
402	40–35–F	12824	510.8	25.10	213.5	14.6	40.00	2400.0	213.55	6.718	5.342	4.710
403	40–40–F	14982	633.6	23.68	213.5	14.6	39.97	2398.2	213.41	6.714	6.260	5.450
410	60–30–F	13348	511.3	26.10	214.1	14.6	60.00	3600.0	320.34	10.077	3.708	3.924
411	60–35–F	16567	705.2	23.50	216.3	14.5	60.00	3600.0	320.34	10.077	4.600	4.600
412	60–40–F	19635	888.8	22.09	216.7	14.5	60.64	3638.4	323.75	10.184	5.400	5.313
405	80–30–F	15110	631.4	23.92	214.2	14.4	80.00	4800.0	427.13	13.435	3.150	3.854
407	80–40–F	23107	1088.8	21.22	213.0	14.6	80.00	4800.0	427.13	13.435	4.815	5.200
408	80–55–F	31485	1257.9	25.01	213.5	14.5	81.28	4876.8	434.00	13.652	6.456	6.060

TABLE 13—TESTS OF PENN R. R.

502	80–$\frac{35}{60}$–F	9323	495.7	18.81	215.2	14.5	80.05	4803.0	336.3	19.14	1.940	.....
505	160–$\frac{25}{45}$–F	10580	524.5	20.18	219.7	14.4	159.96	9597.6	672.1	38.25	1.103	1.305
506	160–$\frac{25}{45}$–F	11219	524.5	21.38	219.6	14.4	160.00	9600.0	672.7	38.26	1.168	1.280
507	160–$\frac{40}{60}$–F	16070	809.3	19.85	214.6	14.7	160.00	9600.0	672.7	38.26	1.674	1.720
508	160–$\frac{50}{70}$–F	19724	944.6	20.89	206.4	14.5	160.00	9600.0	672.7	38.26	2.055	2.075
510	240–$\frac{25}{45}$–F	13246	596.8	22.20	212.5	14.6	240.00	14400.0	1008.3	57.39	0.920	1.266
511	240–$\frac{30}{55}$–F	15014	653.2	23.00	218.9	14.4	240.00	14400.0	1008.3	57.39	1.042	1.305
512	240–$\frac{30}{60}$–F	17574	802.3	21.90	217.5	14.4	239.99	14399.4	1008.2	57.39	1.221	1.470
513	280–$\frac{30}{55}$–F	18710	682.5	27.44	215.0	14.4	279.99	16799.4	1176.1	66.96	1.114	1.311

CLASS W LOCOMOTIVE NO. 585.

High Pressure Cylinder						Low Pressure Cylinder						
Wt. of Steam per Revolution		Quality of Steam Mixture at Cut-off, x_c, parts of unity	Average Value of n, From Expansion Curves	Av. Abs. Pressure, lb.-sq. in.		Weight of Steam per Revolution,			Quality of Steam Mixture at Cut-off, x_c parts of unity	Average Value of n, From Expansion Curves	Av. Abs. Pressure, lb.-sq. in.	
Retained in Compression from Indicator	Total Mixture Actually Present			At Cut-off	Back Pressure of Exhaust near Compression	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture actually present			At Cut-off	Back Pressure of Exhaust near Compression
16	17	18	19	20	21	22	23	24	25	26	27	28
1.268	5.039	0.762	1.091	200	93	3.071	0.450	4.221	0.728	1.063	64	16
1.188	5.236	0.776	1.081	200	90	3.126	0.438	4.486	0.697	1.037	65	15
1.181	5.552	0.779	1.069	200	90	3.410	0.376	4.747	0.718	1.099	71	15
1.163	4.634	0.838	0.998	190	91	2.845	0.514	3.985	0.714	0.955	62	18
1.208	4.326	0.821	1.015	190	87	2.542	0.646	3.764	0.676	0.975	60	18
1.072	4.944	0.860	1.022	185	87	3.252	0.440	4.312	0.754	0.947	60	18
0.988	5.382	0.888	1.045	198	92	3.695	0.481	4.875	0.758	1.015	64	19
1.544	3.717	0.866	1.032	150	104	2.382	0.842	3.015	0.791	1.002	48	24
1.138	3.710	0.965	1.100	140	96	2.900	0.749	3.321	0.874	1.058	50	27
1.386	3.386	0.933	1.090	150	97	2.344	0.771	2.777	0.845	1.011	45	22
1.165	3.492	0.906	1.074	140	100	2.504	0.796	3.123	0.802	0.920	45	25
0.919	3.296	0.928	1.033	115	87	2.582	0.700	3.077	0.827	1.050	45	28

CLASS 900 LOCOMOTIVE NO. 929.

2.489	6.857	0.592	1.002	214	112	3.550	0.943	5.311	0.669	1.168	64	18
2.220	7.562	0.623	1.081	209	111	3.970	0.852	6.194	0.641	1.208	58	18
2.041	8.301	0.656	1.092	212	114	4.588	0.745	7.005	0.655	1.079	64	18
2.526	6.234	0.630	0.993	210	111	3.059	1.086	4.794	0.638	1.036	58	18
2.350	6.950	0.662	0.997	205	114	3.848	0.875	5.475	0.703	1.088	60	17
2.112	7.512	0.708	1.051	209	115	4.454	0.934	6.334	0.704	1.109	62	17
2.760	5.910	0.652	0.948	195	112	3.138	1.111	4.261	0.737	1.041	60	18
2.322	7.137	0.729	1.051	205	112	4.410	0.939	5.754	0.767	1.085	62	19
2.139	8.595	0.705	1.078	205	101	4.864	0.948	7.404	0.657	1.054	58	22

DE GLEHN LOCOMOTIVE NO. 2512.

.....	.....	.....	.....	...	...	1.695	0.266	2.206	0.769	1.047	42	15
0.534	1.637	0.798	1.004	184	42	.....	.....	.....	.....	.....	..	..
0.528	1.696	0.755	0.991	173	43	1.080	0.385	1.553	0.696	0.914	30	17
0.478	2.152	0.800	1.033	188	49	1.502	0.310	1.984	0.758	0.955	37	18
0.426	2.481	0.836	1.060	181	53	1.900	0.311	2.366	0.804	0.998	42	21
0.635	1.555	0.815	1.014	160	53	1.118	0.480	1.400	0.799	0.924	32	19
0.564	1.606	0.813	1.035	169	46	.....	.....	.....	.....	.....	..	..
0.539	1.760	0.836	1.072	173	48	.....	.....	.....	.....	.....	..	..
0.587	1.701	0.772	1.047	168	49	.....	.....	....			..	.

TABLE 14—TESTS OF A. T. & S. F.

Number of Test	Laboratory Designation	Total Moist Steam passing thru Cylinders per hr.	Total I. H. P.	Moist Steam per I. H. P. hr., lb.	Pressure in lb. per sq. in.		Speed				High Pressure Cylinder	
											Wt. of Steam per Revolution	
					In Boiler by Gage	Barometer	Revolutions per min.	Revolutions per hr.	Piston Speed, ft. per min.	Miles per hr.	Passing thru Cylinders	Shown by Indicator at Cut-off
1	2	3	4	5	6	8	10	11	12	13	14	15
601	80–30–F	8537	356.2	23.94	217.6	14.6	80.00	4800.0	346.8	18.79	1.778	2.042
602	80–35–F	10520	479.0	21.96	215.7	14.6	80.00	4800.0	346.8	18.79	2.191	.....
603	80–45–F	12668	470.4	22.20	221.0	14.4	80.00	4800.0	346.8	18.79	2.640	2.613
604	80–55–F	16850	808.4	20.85	220.4	14.5	80.01	4800.6	346.8	18.79	3.511	3.434
605	160–35–F	17290	877.1	19.71	220.6	14.6	160.00	9600.0	693.6	37.59	1.803	2.395
606	160–45–F	20435	999.9	20.43	219.2	14.5	160.00	9600.0	693.6	37.59	2.131	2.550
607	160–55–F	25492	1296.1	19.65	221.9	14.6	160.00	9600.0	693.6	37.59	2.658	.....
609	240–50–F	28645	1414.6	20.25	221.2	14.5	239.89	14393.4	1039.7	56.35	1.989	2.694
611	240–53–F	33691	1621.5	20.76	221.0	14.5	240.02	14401.2	1040.4	56.38	2.338	2.937
613	280–50–F	30680	1459.7	21.01	219.5	14.6	280.00	16800.0	1213.6	65.77	1.825	2.571

TABLE 15—TESTS OF N. Y. C. & H. R.

801	80–35–F	11938	567.4	21.05	209.4	14.5	79.82	4789.2	345.5	18.72	2.495	2.564
802	80–45–F	14797	714.4	20.70	210.8	14.6	80.00	4800.0	346.3	18.76	3.082	3.150
805	160–35–F	19182	967.0	19.85	222.2	14.6	160.00	9600.0	622.6	37.52	1.998	2.458
806	160–45–F	25314	1253.0	20.21	220.4	14.5	160.00	9600.0	622.6	37.52	2.638	3.009
807	160–55–F	33321	1490.5	22.35	221.4	14.4	160.00	9600.0	622.6	37.52	3.473	.....
809	240–35–F	24361	1142.8	21.31	218.7	14.5	240.00	14400.0	1039.1	56.29	1.691	2.311
811	240–50–F	36614	1629.8	22.48	219.6	14.5	239.99	14399.9	1039.0	56.28	2.542	3.004
812	240–55–F	40708	1641.4	24.80	212.3	14.5	240.00	14400.0	1039.1	56.29	2.827	.....
813	280–35–F	26886	1102.3	22.52	220.0	14.5	280.11	16806.6	1212.5	65.69	1.598	2.288
814	280–40–F	31132	1368.9	22.75	220.2	14.5	279.97	16798.2	1212.0	65.66	1.854	2.613
815	320–40–F	32475	1335.7	24.39	222.3	14.5	320.00	19200.0	1385.3	75.05	1.690	2.360

TABLE 16—TESTS OF HANOVER COMPOUND

Number of Test	Laboratory Designation	Total Superheated Steam passing thru Cylinders per hr. lb.	Total I. H. P.	Superheated Steam I. H. P. hr. in lb.	Pressure—lb. per sq. in.			Degrees of Superheat in Branch pipe	Speed			
					In Boiler by Gage	In Branch-pipe by Gage	Barometer		Revolutions per min.	Revolutions per hr.	Piston Speed ft. per Minute	Miles per Hour
1	2	3	4	5	6	7	8	9	10	11	12	13
701	80–35–F	6795	375.6	18.09	198.3	194.6	14.4	84.45	80.00	4800	314.9	18.57
702	80–45–F	8564	480.5	17.84	202.0	198.3	14.4	86.97	80.00	4800	314.9	18.57
705	160–35–F	10470	622.9	16.81	198.8	194.4	14.5	82.18	160.00	9600	629.7	37.13
706	160–40–F	12097	728.9	16.59	202.6	197 4	14.5	103.98	160.06	9603.6	630.0	37.15
707	160–45–F	14533	813.7	17.86	198.8	193.6	14.4	116.20	160.00	9600	629.7	37.13
708	160–45–F	14550	801.3	18.16	197.0	190.9	14.5	97.19	160.00	9600	629.7	37.13
709	240–30–F	10521	631.2	16.67	204.1	198.5	14.5	88.36	240.00	14400	944.7	55.70
711	240–40–F	15343	816.4	18.78	187.0	179.9	14.7	101.46	240.00	14400	944.7	55.70
712	280–30–F	14655	688.4	21 29	204.2	196.6	14.5	71.28	280.27	16816.2	1103.1	65.05

CLASS 507. LOCOMOTIVE NO. 535.

High Pressure Cylinder						Low Pressure Cylinder						
Wt. of Steam per Revolution				Av. Abs. Pressure, lb.-sq. in.		Weight of Steam per revolution					Av. Abs. Pressure, lb.-sq. in.	
Retained in Compression from Indicator	Total Mixture Actually Present	Quality of Steam Mixture at Cut-off, parts of unity	Average Value of *n*, From Expansion Curves	At Cut-off	Back Pressure of Exhaust near Compression	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present	Quality of Steam Mixture at Cut-off, parts of unity	Average Value of *n*, From Expansion curves	At Cut-off	Back Pressure of Exhaust near Compression
16	17	18	19	20	21	22	23	24	25	26	27	28
0.898	2.676	0.764	0.944	218	106	1.389	0.487	2.265	0.614	1.042	59	15
.....	.....	.....	.....	...	...	1.767	0.436	2.627	0.673	1.066	66	15
0.987	3.627	0.721	0.999	218	109	1.976	0.391	3.031	0.652	1.062	62	15
0.943	4.454	0.771	1.076	219	118	2.725	0.331	2.842	0.709	1.140	64	16
1.267	3.070	0.780	1.001	210	100	1.704	0.481	2.284	0.746	1.065	59	16
1.155	3.286	0.776	1.008	194	114	1.945	0.480	2.611	0.745	1.041	65	18
.....	.....	.....	.....	...	...	2.385	0.461	3.119	0.765	1.073	63	18
1.116	3.105	0.868	1.076	195	115	2.072	0.594	2.583	0.803	1.055	59	20
1.068	3.406	0.863	1.039	195	104	2.352	0.584	2.922	0.805	1.024	60	26
1.099	2.924	0.880	1.098	179	104	1.920	0.642	2.467	0.779	1.025	55	25

R. R. CLASS I1 LOCOMOTIVE NO. 3000.

1.011	3.506	0.732	0.986	208	95	1.870	0.451	2.946	0.635	0.976	62	16
0.771	3.793	0.830	1.060	212	89	2.318	0.427	3.509	0.661	1.030	63	16
1.066	3.064	0.802	0.942	201	105	1.762	0.580	2.578	0.684	0.937	58	19
0.924	3.562	0.845	1.097	204	96	2.250	0.546	3.184	0.707	0.982	58	22
.....	.....	.....	.....	...	...	2.910	0.576	4.049	0.719	0.934	63	27
1.188	2.879	0.804	0.968	199	114	1.758	0.741	2.432	0.723	0.930	59	25
0.936	3.478	0.864	1.035	191	102	2.420	0.723	3.267	0.741	0.962	60	31
.....	.....	.....	.....	...	...	2.626	0.713	3.540	0.742	0.950	62	34
1.145	2.743	0.834	0.958	202	113	1.718	0.791	2.389	0.719	0.950	59	26
1.195	3.049	0.858	1.008	199	119	2.064	0.836	2.690	0.767	0.964	59	31
1.209	2.899	0.884	1.059	188	121	1.972	1.018	2.708	0.729	1.000	55	30

CLASS S8 LOCOMOTIVE NO. 628.

High Pressure Cylinder								Low Pressure Cylinder						
Weight of Steam per Revolution						Av. Abs. Pressure, lb.-sq. in.		Weight of Steam per Revolution					Av. Abs. Pressure, lb.-sq. in.	
Passing thru Cylinders	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present	Quality of Steam Mixture at Cut-off Parts of Unity	Average Value of *n* from Expansion Curves	At Cut-off	Back Pressure of Exhaust near compression	Shown by Indicator at Cut-off	Retained in Compression from Indicator	Total Mixture Actually Present	Quality of Steam Mixture at Cut-off Parts of Unity	Average Value of *n* from Expansion Curves	At Cut-off	Back Pressure of Exhaust near Compression
14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1.416	1.465	0.417	1.833	0.801	0.940	188	54	1.287	0.237	1.653	0.779	0.990	42	16
1.784	1.843	0.374	2.158	0.855	0.997	188	55	1.605	0.177	1.961	0.819	1.038	47	15
1.091	1.333	0.430	1.521	0.876	0.944	156	59	1.184	0.299	1.390	0.852	1.029	40	17
1.259	1.514	0.397	1.656	0.914	1.041	160	58	1.331	0.278	1.537	0.867	1.005	40	18
1.514	1.700	0.353	1.867	0.911	1.049	160	55	1.478	0.261	1.775	0.833	1.015	42	19
1.516	1.683	0.386	1.902	0.885	1.000	160	59	1.578	0.279	1.795	0.879	1.058	42	21
0.730	1.091	0.499	1.229	0.888	0.960	145	56	0.990	0.348	1.078	0.918	1.000	36	18
1.065	1.366	0.385	1.450	0.942	1.028	140	55	1.302	0.328	1.393	0.935	1.004	37	22
0.872	1.188	0.498	1.370	0.816	0.946	146	63	1.055	0.406	1.278	0.826	0.997	35	21

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